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Volume II. Internal Combustion Sources

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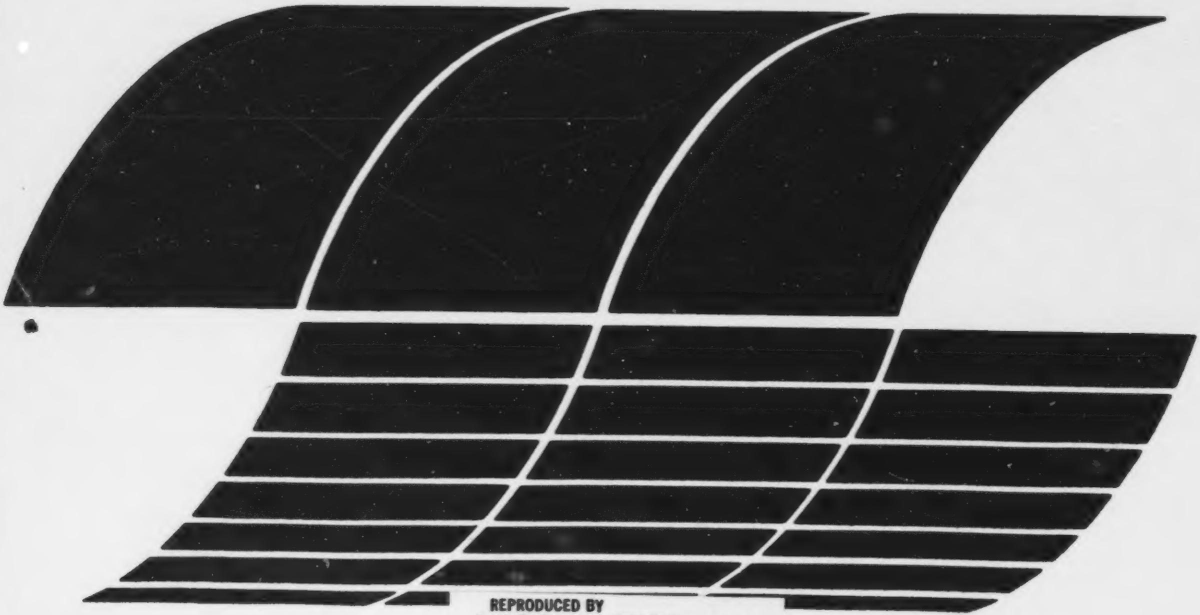

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Emissions Assessment of Conventional Stationary Combustion Systems; Volume II. Internal Combustion Sources

by

C.C. Shih, J.W. Hamersma, D.G. Ackerman,
R.G. Beimer, M.L. Kraft, and M.M. Yamada

TRW, Inc.
One Space Park
Redondo Beach, California 90278

Contract No. 68-02-2197
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EPA Project Officer: Ronald A. Venezia

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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16. ABSTRACT The report gives results of an assessment of emissions from gas- and oil-fueled gas turbines and reciprocating engines for electricity generation and industrial applications. The assessment involved a critical examination of existing emissions data, followed by a measurement program to fill data gaps based on a phased sampling and analysis strategy. In the first phase of the measurement program, a gas-fueled gas turbine, five distillate-oil-fueled gas turbines, and five diesel engines were tested. Evaluation of test results led to the recommendation for additional tests to determine SO3 and organic emissions from diesel engines which were subsequently conducted on three of the diesel engines previously tested. Assessment results indicate that internal combustion (IC) sources contribute significantly to the national emissions burden. NOx, hydrocarbon, and CO emissions from IC sources account for approximately 20, 9, and 1%, respectively, of the emissions of these pollutants from all stationary sources. The sources severity factor (the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists) was used to identify pollutants of environmental concern.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Measurement	Pollution Control	13B	14B
Gas Turbines	Nitrogen Oxides	Stationary Sources	13G	07B
Diesel Engines	Hydrocarbons		21G	07C
Reciprocating Engines				
Electric Power Generation			10A	
Industrial Plants	Carbon Monoxide		13I	
Sulfur Trioxide	Organic Compounds			

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ABSTRACT

Emissions from gas- and oil-fueled gas turbines and reciprocating engines for electricity generation and industrial applications are assessed in this report. The assessment method involved a critical examination of existing emissions data, followed by the conduct of a measurement program to fill data gaps based on a phased sampling and analysis strategy.

In the first phase of the measurement program, one gas-fueled gas turbine, five distillate-oil fueled gas turbines, and five diesel engines were selected for testing. Evaluation of test results led to the recommendation for additional tests to determine SO_3 and organic emissions from diesel engines which were subsequently conducted at three of the diesel engine sites previously tested.

The results of the emissions assessment indicate that internal combustion sources contribute significantly to the national emissions burden. NO_x, hydrocarbon and CO emissions from internal combustion sources account for approximately 20 percent, 9 percent, and 1 percent of the emissions of these pollutants from all stationary sources. The source severity factor, defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists, was used to identify pollutants of environmental concern.

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1. SUMMARY AND CONCLUSIONS

Emissions from gas- and oil-fueled gas turbines and reciprocating engines for electricity generation and industrial applications are assessed in this report. The assessment method involved a critical examination of existing emissions data, followed by the conduct of a measurement program to fill data gaps based on phased sampling and analysis strategy.

The phased approach to environmental assessments is designed to provide comprehensive emissions information on all process waste streams in a cost effective manner. To achieve this goal, two distinct sampling and analysis levels are being employed in this program. Level I utilizes semiquantitative (± a factor of 3) techniques of sample collection and laboratory and field analyses to: provide preliminary emissions data for waste streams and pollutants not adequately characterized; identify potential problem areas; and prioritize waste streams and pollutants in those streams for further, more quantitative testing. Using the information from Level I, available resources can be directed toward Level II testing which involves specific, quantitative analysis of components of those streams which do contain significant pollutant loadings. The data developed at Level II is used to identify control technology needs and to further define the environmental hazard associated with each process stream. A third phase, Level III, which is outside the scope of this program, employs continuous or periodic monitoring of specific pollutants identified at Level II so that the emission rates of these critical components can be determined exactly as a function of time and operating conditions.

1.1 INTERNAL COMBUSTION SOURCE DESCRIPTION

Stationary internal combustion sources for electricity generation and industrial applications are grouped into two categories: gas turbines and reciprocating engines. Gas turbines may be classified into three general types: simple open cycle, regenerative open cycle, and combined cycle.

Regenerative type gas turbines constitute only a very small fraction of the total gas turbine population. Emissions from identical gas turbines used in the combined cycle and in the simple cycle are the same. Therefore, only emissions from simple cycles need to be evaluated.

Reciprocating internal combustion engines may be classified into spark and compression ignition (diesel) engines. All distillate oil reciprocating engines are compression ignited, and all gasoline reciprocating engines are spark ignited. Spark ignition gasoline engines have very limited use for electricity generation and industrial application because of their poor part load economy and cost of fuel. Gas reciprocating engines, with the exception of the dual-fuel type, are spark ignited. Gas can only be used in a compression ignition engine if a small amount of diesel fuel is injected into the compressed air/gas mixture to initiate combustion.

The principal application areas for gas turbines and reciprocating engines are: electricity generation, oil and gas transmission, natural gas processing, oil and gas production and exploration. For gas turbines, the total 1978 installed capacity is 50,800 MW for electricity generation and 9,400 MW for industrial applications. For reciprocating engines, the total 1978 installed capacity is 5,300 MW for electricity generation and 19,500 MW for industrial applications.

The current average size of electricity generation gas turbines is approximately 31 MW. As of December 31, 1976, the capacity average age for electricity generation gas turbines was approximately 5 years. Industrial gas turbines were estimated to have an average size of 2.2 MW. For reciprocating engines, the average size unit for electricity generation is 1.9 MW (2,500 HP), and the average size unit for oil and gas transmission is 1.5 MW (2,000 HP). Average age for reciprocating engines is approximately 10 years.

Air pollution control equipment is generally not installed on gas turbines or reciprocating engines. However, there is increasing recognition that water and steam injection are valid techniques for controlling NO_x emissions from gas turbines. In addition, to reduce visible smoke emissions from oil-fueled gas turbines, fuel additives such as soluble compounds of barium, manganese and iron are often employed.

1.2 THE EXISTING EMISSIONS DATA BASE

Air emissions from the flue gas stacks are the only significant emissions from electricity generation and industrial gas turbines and reciprocating engines. A major task in this program has been the identification of gaps and inadequacies in the existing data base for these flue gas emissions. Decisions as to the adequacy of the data base were made using criteria developed by considering both the reliability and variability of the data. Estimated environmental risks associated with the emission of each pollutant were also considered in the determination of the need for, and extent of, the phased sampling and analysis program.

The evaluation of emissions data has indicated that the existing emissions data base is adequate for gas-fueled turbines and reciprocating engines. For distillate oil-fueled gas turbines, the existing data base for NO_x, total hydrocarbons, CO, particulate, SO_2 and SO_3 emissions is adequate. However, the existing data base for trace elements and specific organic emissions was inadequate. For distillate oil reciprocating engines, the existing data base for NO_x, total hydrocarbons, CO, and SO_2 emissions is adequate. The existing data base for particulates, SO_3, trace elements and specific organic emissions was found to be inadequate.

1.3 THE SOURCE MEASUREMENT PROGRAM

Because of the deficiencies in the existing emissions data base, eleven internal combustion sites were selected for testing to provide a better characterization of the emissions associated with these sources. The sites tested included one gas-fueled gas turbine, five distillate oil-fueled gas turbines, and five distillate oil reciprocating engines (diesel engines). A gas-fueled gas turbine site was included to assure that previously unidentified pollutants are not being emitted in environmentally unacceptable quantities. Specific sites were chosen based on the representativeness of the sites as measured against the important characteristics of systems within each source category, including engine model, rated capacity, age and pollution control method.

Test results from the first phase were evaluated to determine the need for and type of additional sampling and analysis. These evaluations led to the recommendation of additional tests to determine SO_3 and organic emissions from electricity generation distillate oil reciprocating engines. Level II tests were subsequently conducted at three of the diesel engine sites previously tested.

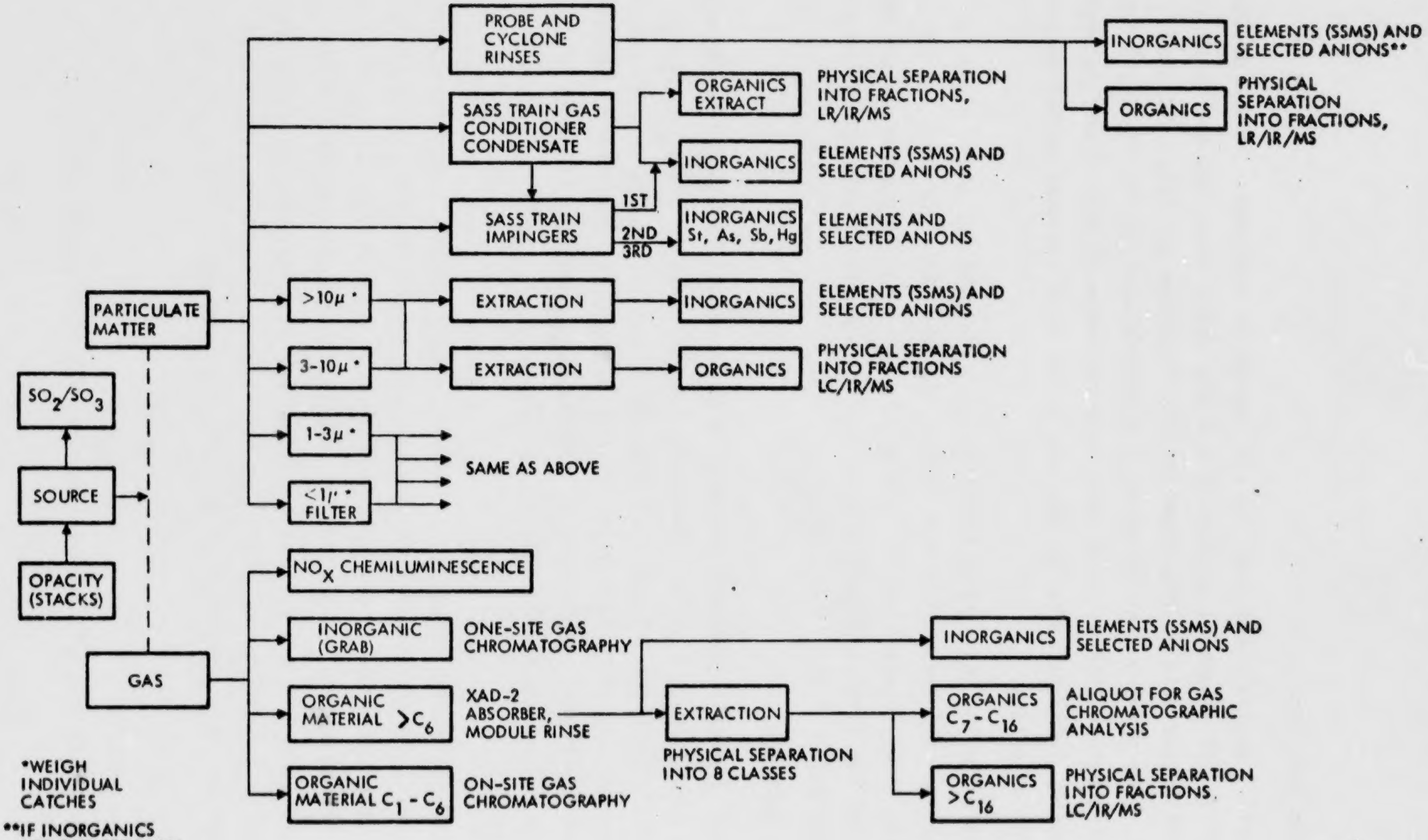
1.3.1 Level I Field Testing

The Source Assessment Sampling System (SASS) train, developed under contract to EPA, was used to collect both vaporous and particulate emissions in quantities sufficient for the wide range of analyses needed to adequately characterize emissions from internal combustion sources. Briefly, the SASS train consists of a conventional heated probe, three cyclones and a filter in a heated oven which collect four particulate size fractions, a gas conditioning system, an XAD-2 polymer adsorbent trap to collect gaseous organics and some inorganics, and impingers to collect the remaining gaseous inorganics and trace elements. The train is run until at least 30 m^3 of gas has been collected. This criterion was established in conjunction with analytical technique sensitivities, to ensure that any emission which would increase the ambient loading by more than 1 $\mu g/m^3$ will be detected. The cyclones were deleted as particulate loadings were too low to provide weighable quantities of samples in each cyclone.

In addition to using the SASS train for stack gas sampling, other equipment was employed to collect those components not analyzable from the train samples. A gas chromatograph (GC) with ionization detection was used in the field to analyze C_1-C_6 hydrocarbons collected in gas sampling bags. Additionally, these samples were analyzed for CO, CO_2, O_2 and SO_2 by GC using a thermal conductivity detector.

1.3.2 Modified Level I Laboratory Analysis

The basic Level I sampling and analytical plan for particulate and gaseous emissions is depicted in Figure 1. A brief description of inorganic and organic analyses performed and the deviations from the basic Level I procedure follows.


PROBE AND CYCLONE RINSES
SASS TRAIN GAS CONDITIONER CONDENSATE
SASS TRAIN IMPINGERS
1ST
2ND
3RD
PARTICULATE MATTER
SO2/SO3
SOURCE
OPACITY (STACKS)
GAS
>10μ *
3-10μ *
1-3μ *
<1μ * FILTER
EXTRACTION
EXTRACTION
SAME AS ABOVE
INORGANICS
ELEMENTS (SSMS) AND SELECTED ANIONS**
ORGANICS
PHYSICAL SEPARATION INTO FRACTIONS, LR/IR/MS
ORGANICS EXTRACT
PHYSICAL SEPARATION INTO FRACTIONS, LR/IR/MS
INORGANICS
ELEMENTS (SSMS) AND SELECTED ANIONS
INORGANICS St, As, Sb, Hg
ELEMENTS AND SELECTED ANIONS
INORGANICS
ELEMENTS (SSMS) AND SELECTED ANIONS
ORGANICS
PHYSICAL SEPARATION INTO FRACTIONS LC/IR/MS
NOX CHEMILUMINESCENCE
INORGANIC (GRAB)
ONE-SITE GAS CHROMATOGRAPHY
ORGANIC MATERIAL >C6
XAD-2 ABSORBER, MODULE RINSE
ORGANIC MATERIAL C1 - C6
ON-SITE GAS CHROMATOGRAPHY
EXTRACTION
PHYSICAL SEPARATION INTO 8 CLASSES
INORGANICS
ELEMENTS (SSMS) AND SELECTED ANIONS
ORGANICS C7 - C16
ALIQUOT FOR GAS CHROMATOGRAPHIC ANALYSIS
ORGANICS >C16
PHYSICAL SEPARATION INTO FRACTIONS LC/IR/MS

*WEIGH INDIVIDUAL CATCHES

**IF INORGANICS ARE GREATER THAN 10% OF TOTAL CATCH.

Figure 1. Basic Level 1 Sampling and Analytical Plan for Particulates and Gases

Inorganic Analyses--

Level I analysis was used for all inorganics analyses. It was designed to identify all elemental species in the SASS train fractions and to provide semiquantitative data on the elemental distributions and total emission factors. The primary tool for Level I inorganic analysis is the Spark Source Mass Spectrograph (SSMS). SSMS data were supplemented with Atomic Absorption Spectrometry (AAS) data for Hg, As, and Sb and with standard method determinations for chlorides.

The following SASS train fractions were analyzed for their elemental composition: (1) the particulate filter, (2) the XAD-2 sorbent, and (3) a composite sample containing portions of the XAD-2 module condensate and HNO_3 rinse, and the first impinger solution. Fuel was also analyzed for the oil-fired sources.

Organic Analyses--

Level I organic analysis provides data on volatile (C_7-C_{16}) and nonvolatile organic compounds (> C_{16}) to supplement data for gaseous organics (C_1-C_6) measured in the field. Organics in the XAD-2 module condensate trap and XAD-2 resin were recovered by methylene chloride extraction. SASS train components including the tubing were carefully cleaned with methylene chloride or methylene chloride/methanol solvent to recover all organics collected in the SASS train.

Because all samples are too dilute to detect organic compounds by the majority of instrumental techniques employed, the first step in the analysis was to concentrate the sample fractions from as much as 1000 ml to 10 ml in a Kuderna-Danish apparatus in which rinse solvent is evaporated while the organics of interest are retained*. Kuderna-Danish concentrates were then evaluated by gas chromatography (GC), infrared spectrometry (IR), liquid chromatography (LC), gravimetric analysis, and sequential gas chromatography/

---

* Kuderna-Danish is a glass apparatus for evaporating bulk amounts of solvents.

mass spectrometry (GC/MS)*. The extent of the organic analysis is determined by the stack gas concentrations found for total organics (volatile and non-volatile). If the total organics indicate a stack gas concentration below 500 µg/m^3, further analysis is not conducted. If the concentration is above 500 µg/m^3, a class fractionation by liquid chromatography is conducted followed by GC and IR analyses.

The organic analysis plan is compatible with the performance of additional Level II analyses at several points. For example, in the case of internal combustion sources, polycyclic organic matter (POM) emission information was desired and aliquots of concentrates from various portions of the SASS train were analyzed for these species by GC/MS.

1.3.3 Level II Field Testing

At each of the diesel engine sites, the Goksoyr-Ross controlled condensation train was used for the measurement of oxidized sulfur emissions. In this approach, SO_3 is separated from the gas stream by cooling the flue gas below the dew point for SO_3 (H_2SO_4) but above the dew point of water. Particulate matter (including metallic sulfates) is removed by means of a heated quartz glass filter in a filter holder kept above 260°C. A condensation coil for SO_3 (H_2SO_4) collection is maintained at 60°C by a water circulation bath. The SO_2 is removed in impingers filled with H_2O_2.

Organic samples were acquired using the SASS train without cyclones. Other changes made included the addition of acetone in the organic sample recovery washes and the omission of isopropyl alcohol from the impinger recovery washes.

1.3.4 Level II Laboratory Analysis

Organic Analysis--

The primary tool used was gas chromatography/mass spectrometry (GC/MS) with capillary column chromatography. All samples were analyzed in this capillary column without additional preparation other than the introduction of an internal standard.

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* The major modification in the Level I sampling and analysis procedure was the GC/MS analysis for POM's.

In conjunction with capillary column analysis, several liquid chromatography (LC) fractions were analyzed by GC/MS using both electron impact (EI) and chemical ionization (CI) modes of ionization. The purpose of analyzing LC fractions was to identify compounds present at low concentration levels in specific compound classes. Once identification was made, that specific compound was searched for in the data obtained in the original sample. This procedure was used to facilitate identification of species at low concentration levels in rather concentrated samples. When no evidence of the compound was found in the original sample, it was assumed to be a contaminant introduced as part of the LC procedure. Compounds confirmed to be present in the original sample, on the other hand, were quantified and reported.

Analysis for Sulfur Species--

Sulfur species collected in the Goksoyr-Ross controlled condensation train were analyzed for emissions of SO_2, SO_3 and particulate sulfate from diesel engines. Sulfur trioxide, collected as H_2SO_4 in the controlled condensation coil, was determined by a bromophenol blue indicated acid-base titration. Sulfur dioxide, collected in the H_2O_2 impinger, reacted to form H_2SO_4 and was subsequently determined by the turbidimetric sulfate analysis. Particulate sulfates collected on the filter and from the probe rinse were also determined by the turbidimetric sulfate analysis.

1.3.5 Results

The results of the field measurement program along with supplementary values for certain pollutants obtained from the existing data base are summarized in Tables 1 and 2.

Tables 1 and 2 also list severity factors, defined as the ratio of the calculated maximum ground level concentrations of the pollutant species to the level at which a potential environmental hazard exists. A severity factor of greater than 0.05 is indicative of a potential problem requiring further attention. As can be seen from Tables 1 and 2, the major pollutant from

TABLE 1. SUMMARY OF RESULTS OF EMISSIONS ASSESSMENT FOR GAS-FUELED INTERNAL COMBUSTION SOURCES

Pollutant	Gas-Fueled Gas Turbines				Gas Reciprocating Engines			
	Elec. Gen.		Industrial		Elec. Gen.		Industrial	
	Emission Factor (ng/J)	Severity Factor	Emission Factor (ng/J)	Severity Factor	Emission Factor (ng/J)	Severity Factor	Emission Factor (ng/J)	Severity Factor
NO_x	168	0.17	130	0.52	1549	7.1	1549	5.7
Total hydrocarbons	23.2	0.020	8.6	0.025	528	1.7	528	1.3
CO	64.8	0.0003	48.8	0.0007	340	0.0051	340	0.0040
Particulate	5.1	0.0019	5.1	0.0062	5.7	0.0068	5.7	0.0055
SO_x	0.26	<0.0001	0.26	<0.0001	0.26	0.0002	0.26	0.0002

TABLE 2. SUMMARY OF RESULTS OF EMISSIONS ASSESSMENT FOR OIL-FUELED INTERNAL COMBUSTION SOURCES

Pollutant	Distillate Oil-Fueled Gas Turbines				Distillate Oil Reciprocating Engines			
	Elec. Gen.		Industrial		Elec. Gen.		Industrial	
	Emission Factor (ng/J)	Severity Factor	Emission Factor (ng/J)	Severity Factor	Emission Factor (ng/J)	Severity Factor	Emission Factor (ng/J)	Severity Factor
NO_x	311	0.32	207	0.83	1392	6.4	1392	5.1
Total hydrocarbons	17.5	0.015	3.6	0.010	52	0.16	52	0.13
CO	43.8	0.0002	101	0.0014	266	0.0040	266	0.0032
Particulate	13.0	0.0049	13.0	0.016	14.1	0.019	14.1	0.015
SO_x	33.1	0.0089	33.1	0.029	101	0.097	101	0.077
SO_3	1.5	0.056	1.5	0.18	1.8	0.23	1.8	0.18
Trace Elements								
Copper	0.58	0.085	0.58	0.28	0.45	0.23	0.45	0.20
Nickel	0.53	0.16	0.53	0.51	0.56	0.60	0.56	0.48
Phosphorus	0.13	0.037	0.13	0.12	0.097	0.10	0.097	0.082

internal combustion turbines and reciprocating engines is nitrogen oxides. For reciprocating engines, emissions of total hydrocarbons are also significant, especially in the case of gas-fueled engines. Source severity factors for SO_2 emissions from diesel engines, and for SO_3 emissions (in the form of sulfuric acid vapor and aerosols) from oil-fueled gas turbines and reciprocating engines are all greater than 0.05, indicating the environmental significance of emissions of sulfur species.

Trace element emissions from the gas-fueled gas turbine tested were insignificant. For oil-fueled gas turbines and reciprocating engines, sodium, calcium, nickel, copper, iron, zinc and silicon were the trace elements emitted in the largest quantities. Nickel, copper, and phosphorus were found to be the only trace elements with severity factors greater than 0.05.

Data for polycyclic organic matter (POM) emissions obtained by GC/MS are not reported in the summary tables. POM's were not detected in the emissions from the one gas-fueled gas turbine and the five distillate oil-fueled gas turbines tested. POM emissions from the five diesel engines tested were found to be mostly naphthalenes and substituted naphthalenes. Emissions of these organic species resulted in calculated source severity factors which were all well below 0.05. POM compounds known to be carcinogenic, such as benzo(a)-pyrene and dibenz(a,h)anthracene, were not found above the detection limit of 0.05 $\mu g/m^3$.

1.4 CONCLUSIONS

Several conclusions, as listed below, can be drawn from the emissions assessment of electricity generation and industrial internal combustion sources:

- NO_x emissions from stationary internal combustion sources are a potential environmental problem. These emissions account for approximately 20 percent of the total NO_x emissions from stationary sources. Of the NO_x emissions from internal combustion sources, more than 80 percent are contributed by the industrial reciprocating gas engine category. Source severity factors for NO_x emissions from gas turbines and reciprocating engines range from 0.17 to 7.1.

- Emissions of hydrocarbons from stationary internal combustion sources contribute significantly to the national emissions burden. These emissions account for approximately 9 percent of the total hydrocarbon emissions from stationary sources. More than 80 percent of the hydrocarbon emissions from internal combustion sources are contributed by the industrial reciprocating gas engine category. Source severity factors for hydrocarbon emissions range from 0.01 for industrial gas-fueled gas turbines to 1.7 for industrial reciprocating gas engines.

- CO emissions from stationary internal combustion sources are not an environmental concern. Source severity factors for CO emissions from internal combustion sources are all well below 0.05. Total CO emissions from these sources account for approximately 1 percent of CO emissions from all stationary sources. More than 80 percent of the CO emissions from internal combustion sources are contributed by the industrial reciprocating gas engine category.

- Emissions of SO_2 and particulates from stationary internal combustion sources contribute only an insignificant fraction of the emissions of these pollutants from stationary sources. Source severity factors for SO_2 and particulate emissions are well below 0.05, with the exception of SO_2 emissions from diesel engines. Source severity factors for SO_2 emissions from industrial and electricity generation diesel engines are 0.08 and 0.10, respectively.

- Combination of emissions data from this measurement program and the existing data base provides adequate characterization of emissions of criteria pollutants from stationary internal combustion sources.

- SO_3 emissions from oil-fueled internal combustion sources require further attention. Source severity factors for SO_3 emissions range from 0.05 to 0.23. For distillate oil-fueled gas turbines, an average of 3.8 percent of the sulfur present in the fuel is converted to SO_3. For diesel engines, an average of 1.4 percent of the fuel sulfur is converted to SO_3. The percent of fuel sulfur converted to SO_3 is lower for diesel engines because of the lower oxygen level in reciprocating engines.

- For distillate oil-fueled gas turbines, the data base for SO_3 emissions is adequate. For distillate oil reciprocating engines, the data base for SO_3 emissions could be improved by additional field tests.

- Emissions of trace elements from gas-fueled internal combustion sources are negligible when compared with emissions of trace elements from oil-fueled sources. For oil-fueled internal combustion sources, emissions of copper, nickel and phosphorus have source severity factors greater than 0.05.

- The data base for trace element emissions from stationary diesel engines is adequate. For distillate oil-fueled gas turbines, trace elements for which the emissions data base is inadequate include nickel, phosphorus and silicon. The emissions data base for these trace elements may be improved by analysis of additional fuel samples.

- Emissions of individual organic species from stationary internal combustion sources are environmentally insignificant. Analyses of organic samples have indicated that organic emissions from oil-fueled internal combustion sources consist mainly of saturated and unsaturated aliphatic and aromatic hydrocarbons. The most prevalent organic species present are saturated straight chain and branched hydrocarbons. Substituted benzenes are the second most abundant organic species emitted. Source severity factors for these organic emissions are well below 0.05.

- POM emissions from internal combustion sources are not at levels of environmental concern. POM emissions from gas- and oil-fueled gas turbines were at levels too low to be differentiated from blank values. For diesel engines, the POM's emitted were mostly naphthalenes and substituted naphthalenes, with source severity factors well below 0.05. POM compounds known to be carcinogenic, such as benzo(a)pyrene and dibenz(a,h)anthracene, were not found above the detection limit of 0.05 $\mu g/m^3$.

2. INTRODUCTION

Conventional stationary combustion systems are major sources of pollutant emissions to air, water, and land. A preliminary assessment of the significance of stationary combustion systems as sources of pollution has been made (Reference 1), and it was estimated that these combustion sources contribute a major portion of the total man-made emissions of nitrogen oxides, sulfur oxides, and particulates. The preliminary assessment also identified the general inadequacy of the emissions data base for a number of potentially hazardous pollutants, including trace elements, sulfur trioxide and particulate sulfate, and polycyclic organic matter (POM).

The overall objective of the current program is to provide a comprehensive assessment of all emissions from selected conventional stationary combustion systems. The assessment process is based on a critical examination of existing data, followed by a phased sampling approach to resolve data gaps. In the first phase, sampling and analysis procedures are used to provide results accurate to a factor of 3 so that preliminary assessments can be made and problem areas identified. The methodology employed is similar to the Level I sampling and analysis procedures developed under the direction of the Industrial Environmental Research Laboratory of the U.S. Environmental Protection Agency (Reference 2), the major deviation being that GC/MS analysis for POM's is performed on the samples collected in this program. Evaluation of results from the first phase will determine all waste stream/pollutant combinations requiring a more detailed and accurate Level II sampling and analysis program. The characterization of combustion source emissions from this program will allow EPA to determine the environmental acceptability of combustion waste streams and pollutants and the need for control of environmentally unacceptable pollutants.

The combustion source types to be assessed in this program has been selected because of their relevance to emissions and because they are among the largest, potentially largest, or most numerous (in use) of existing combustion source types. A total of 51 source types have been selected for study. Selected source types have been classified under the following principal categories:

1) Electricity generation - External combustion
2) Industrial - External combustion
3) Electricity generation and industrial - Internal combustion
4) Commercial/institutional - Space heating
5) Residential - Space heating

These five principal categories have been further divided into subcategories based on fuel type, furnace design, and firing method. The subcategorization is needed because of the differences in the emission characteristics of combustion source types.

This program report is the second in a series of five reports, and is concerned with the emissions assessment of electricity generation and indusrial internal combustion sources. A total of eight combusion source types are considered*:

1.3.22.0.0	Electricity Generation Internal Combustion Distillate Oil-Fueled Gas Turbine
1.4.22.0.0	Electricity Generation Internal Combustion Distillate Oil Reciprocating Engine
1.3.30.0.0	Electricity Generation Internal Combustion Gas-Fueled Gas Turbine
1.4.30.0.0	Electricity Generation Internal Combustion Gas Reciprocating Engine
2.3.22.0.0	Industrial Internal Combustion Distillate Oil-Fueled Gas Turbine
2.4.22.0.0	Industrial Internal Combustion Distillate Oil Reciprocating Engine

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* The I.D. code refers to the classification code used in Reference 1.

2.3.30.0.0 Industrial Internal Combustion Gas-Fueled Gas Turbine

2.4.30.0.0 Industrial Internal Combustion Gas Reciprocating Engine

The approach utilized in the emissions assessment of electricity generation and industrial internal combustion sources is similar to that utilized for the assessment of other combustion source types. First, available information concerning the process and population characteristics of internal combustion sources and their emissions was assembled and assessed to determine the adequacy of the available data base. Sampling and analysis was then conducted at selected representative sites (one gas-fueled gas turbine, five distillate oil-fueled gas turbines, and five distillate oil reciprocating engines) to resolve problem areas arising from inadequacies in the existing data base. The results were evaluated to determine the need for and type of additional sampling and analysis, and to identify the environmentally significant substances emitted from internal combustion sources. These evaluations led to the recommendation of additional tests to determine SO_3 emissions and organic emissions from electricity generation distillate oil reciprocating engines. Three Level II tests for this source category were subsequently conducted. Results from these tests were evaluated to ensure that the emissions data base has been adequately characterized. Lastly, emissions data obtained from the sampling and analysis program were combined with existing emissions data to provide estimates of current and future nationwide emissions of pollutants from internal combustion sources.

3. SOURCE DESCRIPTION

Stationary internal combustion engines, in which the products of combustion of the fuel comprise the working fluid, are usually classified according to the method of transformation of the fluid energy into mechanical work or power. On this basis, internal combustion sources for electricity generation and industrial application are grouped into two types: gas turbines and reciprocating engines. To provide a better understanding of the emission problems associated with stationary internal combustion engines, brief descriptions of the engine types and variations, fuel characteristics, principal applications, installed capacity, and future market trends are provided. Population characteristics of utility and industrial gas turbines and reciprocating engines, including average size and age and the prevalence of pollution control equipment, were used to aid in the selection of representative test facilities.

3.1 PROCESS CHARACTERISTICS

A basic gas turbine consists of a compressor, a combustor and a turbine. High pressure air is supplied by the compressor to the combustor. Fuel is mixed with the air in the combustor and burned. Combustion products are then expanded through the turbine to drive a rotor and generate power. A variety of advanced models have evolved from the simple gas turbine, and are classified into three general operating cycles: simple open cycle, regenerative open cycle and combined cycle. In the simple open cycle, the hot gas discharged from the turbine is exhausted to the atmosphere. In the regenerative open cycle, the gas discharged from the turbine is passed through a heat exchanger to preheat the combustion air. Preheating the air increases the efficiency of the turbine. In the combined cycle, the gas discharged from the turbine is used as auxiliary heat for a steam cycle. The combined cycle system offers a great increase in the combined efficiency of the overall system.

Gas turbines use gas or liquids such as distillate oil and kerosene as fuel. In open cycle gas turbines, where the products of combustion come in direct contact with the turbine blades, the fuel used must result in combustion gases that are free of corrosive ash and large particulates (>2 μm) which cause erosion. The metallic contaminants in fuel that form relatively low melting compounds during combustion must, therefore, be eliminated because the resulting compounds would stick on the turbine blades and corrode the protective oxide coatings. For these reasons, the ASTM Gas Turbine Fuels Committee has set fuel impurity limits for the five critical trace elements: sodium, potassium, lead, vanadium and calcium.

Reciprocating internal combustion engines may be classified according to the method of ignition into spark ignition and compression ignition engines. In spark ignition engines, the fuel is usually mixed with the air at the intake valve (for gaseous fuels) or in a carburetor (for liquid fuels), although occasionally the fuel is injected into the compressed air in the cylinder. In compression ignition engines, on the other hand, only air is taken into the engine on the intake stroke and compressed to ignition conditions. Diesel fuel is then atomized directly into the combustion chamber at a controlled rate. Ignition is spontaneous.

For reciprocating internal combustion engines, the spark ignition engines use gas or volatile liquids such as gasoline as fuel, whereas the compression ignition engines use liquid fuels of low volatility such as low-grade kerosene and distillate oil (diesel fuel). All distillate oil reciprocating engines are compression ignited, and all gasoline reciprocating engines are spark ignited. Spark ignited gasoline engines have very limited use for electricity generation and industrial application, because of their poor part-load economy and demand for premium fuel. Gas reciprocating engines are mostly spark ignited, but as can also be used in a compression ignition engine if a small amount of diesel fuel is injected into the compressed air/gas mixture to initiate combustion. Such compression ignition engines are known as dual-fuel engines, and are normally designed to burn any mixture ratio of gas and diesel fuel. Most of the large bore, high power engines for utility and industrial applications are four-stroke cycle compression ignition engines designed to operate on diesel fuel or dual-fuel, and either two stroke cycle or four-stroke cycle spark ignited gas engines.

3.2 INDUSTRY PROFILE

The principal application areas and the major manufacturers for utility and industrial gas turbines and reciprocating engines are presented in Tables 3 and 4. On the basis of total installed horsepower, electricity generation is the predominant user of gas turbines. For 1976, the Federal Power Commission (FPC) reported a generation capacity of 46,576 MW for gas turbine plants owned by utilities (Reference 4). Utilizing the 1976 FPC figure and the increase in capacity projected by the National Electric Reliability Council (Reference 5), the estimated 1978 generating capacity is 50,800 MW for gas turbine plants owned by utilities. Of the installed capacity, approximately 82 percent are oil-fueled combustion turbines, 7 percent are gas-fueled combustion turbines, and 11 percent are combined cycle plants (Reference 5). For industrial applications, Energy and Environmental Analysis, Inc. (EEA), has indicated that the total gas turbine horsepower installed through 1974 for the oil and gas industry, less electric power generation, amounted to approximately 6,831,000 HP or 5,096 MW (Reference 6). The total generating capacity for the oil and gas industry in 1974 was approximately 460 MW. Analysis of the data published by the Oil and Gas Journal showed that from 1974 to 1976, the gas turbine capacity for gas pipelines increased by a modest 2.86 percent (References 7, 8 and 9). Assuming the same percentage increase in gas turbine capacity for the other turbine applications, the total 1978 gas turbine installed horsepower for the oil and gas industry is estimated to be 7,227,000 HP or 5,392 MW, plus an additional 487 MW for electricity generation. For other industrial applications, EEA data indicated a 1974 total of 1,146,000 HP or 855 MW for industrial drive type gas turbine applications and approximately 1,900 MW for private industry electricity generation (Reference 6). Using a 6 percent annual growth rate, the 1978 total would be 1,447,000 HP or 1,079 MW for industrial drive type gas turbine applications and 2,400 MW for private industry electricity generation.

TABLE 3. PRINCIPAL APPLICATIONS AND MAJOR MANUFACTURERS OF UTILITY AND INDUSTRIAL GAS TURBINES (Reference 3)

Size Category	Principal Applications	Major Manufacturers
< 1,000 HP	Compressor and pump drive, standby electricity generation	Garrett AiResearch
1,000-5,000 HP	Oil and gas transmission, natural gas processing, standby electricity generation, private industry electricity generation, compressor and pump drive	Solar Division of International Harvester, Detroit Diesel Allison Division of General Motors, Avco Lycoming
5,000-20,000 HP	Oil and gas transmission, natural gas processing, standby electricity generation, private industry electricity generation	General Electric, Turbo Power and Marine Systems, Westinghouse
> 20,000 HP (~ 15 MW)	Peak load electricity generation	General Electric, Turbo Power and Marine Systems, Westinghouse
Combined cycle > 100 MW	Base load electricity generation	General Electric, Turbo Power and Marine Systems, Westinghouse

TABLE 4. PRINCIPAL APPLICATIONS AND MAJOR MANUFACTURERS OF UTILITY AND INDUSTRIAL INTERNAL COMBUSTION RECIPROCATING ENGINES (Reference 6)

Size Category	Principal Applications	Major Manufacturers
400-1,000 HP (Medium engines)	Oil and gas production and exploration, natural gas processing, compressor and pump drive, private industry electricity generation, standby electricity generation	Detroit Diesel Allison Division of General Motors, White Superior, Allis-Chalmers, Caterpillar, Cummins, Waukesha
> 1,000 HP (Large engines)	Oil and gas transmission, natural gas processing, peak load and base load electricity generation, nuclear standby power	Cooper-Bessemer, Electromotive Division of General Motors, Ingersoll-Rand, White-Superior, Alco, Colt, Enterprise, Dresser-Clark

Utilities will continue to dominate the gas turbine market in the future. The National Electric Reliability Council (NERC) has surveyed its members for major generating unit additions scheduled for the 1978-1985 period, and projected a 18.3 percent increase in oil-fueled combustion turbine capacity, a 14.7 percent decrease in gas-fueled combustion turbine capacity, a 133.3 percent increase in oil-fueled combined cycle plant capacity, and a 25.8 percent decrease in gas-fueled combined cycle plant capacity from 1978 to 1985 (Reference 5). These figures are used in the estimation of the projected 1985 installed capacity for utility gas turbines, as presented in Table 5. For the oil and gas industry, the gas turbine power added per year for transmission has decreased sharply over the last few years. Extrapolating from the 2.86 percent increase in installed gas turbine capacity from 1974 to 1976, the increase in installed gas turbine capacity from 1978 to 1985 would be 11.0 percent, and the total 1985 gas turbine capacity for the oil and gas industry would be 5,950 MW plus an additional 540 MW for electricity generation. For other industrial applications, the 1985 installed capacity is estimated by assuming a 6 percent annual growth rate. The 1978 and projected 1985 installed gas turbine capacity for utility and industrial applications are compared in Table 5. As noted in Table 5, the total projected 1985 installed capacity of 74,070 MW represents a modest 3.0 percent annual growth rate over the 1978 installed capacity of 60,160 MW. In both 1978 and 1985, the gas turbine installed capacity for the utility sector amounts to approximately 84 percent of the total installed capacity.

On the basis of installed horsepower, the principal applications of reciprocating engines are oil and gas transport, oil and gas production, and electricity generation. For 1976, FPC reported a generation capacity of 5,298 MW for internal combustion reciprocating engine plants owned by utilities (Reference 4). This installed capacity is expected to stay at approximately the same level for 1978. The major use of utility reciprocating engines is for base load electricity generation by municipal power companies, often in areas where demand does not justify the construction of large steam power plants. The majority of new reciprocating engine orders, however, is for nuclear standby power, where the high power diesel engines have dominated the market. In a standards support and environmental impact statement for reciprocating internal combustion engines document prepared for EPA, the 1975 installed capacity for industrial applications was estimated (Reference 6). The data have been projected to 1978 by assuming a 1.6 percent annual increase in installed capacity for all industrial applications, based on analysis of the data published by the Oil and Gas Journal which showed that the reciprocating engine capacity for oil and gas transmission increased by 1.6 percent from 1975 to 1976 (References 8 and 9). Estimations of the 1978 installed reciprocating engine capacity for industrial applications are presented in Table 6. The diesel engine predominates the utility market whereas the spark-ignited gas engine predominates the industrial market.

For the nine-year period from 1976 to 1985, the Federal Power Commission estimated that the net installed capacity for utility reciprocating engines would only increase by approximately 100 MW (Reference 10). Reciprocating engines in the natural gas industry are used primarily to power compressors used in collecting gas from wells, pipeline transportation, underground storage and gas processing plants. Recent sales data have indicated that most of

TABLE 5. CURRENT AND PROJECTED GAS TURBINE INSTALLED CAPACITY FOR UTILITY AND INDUSTRIAL APPLICATIONS

Application Area	Installed Capacity 1978	 1985
Utilities		
Oil-fueled combustion turbine	41,500 MW	49,100 MW
Gas-fueled combustion turbine	3,410 MW	2,910 MW
Oil-fueled combined cycle	3,760 MW	8,770 MW
Gas-fueled combined cycle	2,130 MW	1,580 MW
Oil and gas industry	5,390 MW	5,950 MW
Private industry electricity generation		
Oil and gas industry	490 MW	540 MW
Other industry	2,400 MW	3,600 MW
Other industrial applications	1,080 MW	1,620 MW
Total	60,160 MW	74,070 MW

the sales of reciprocating engines to oil and gas pipelines were for additions to, or replacement of, existing compressor stations (Reference 6). In addition, natural gas production is expected to decline in the 1978-1985 period. There has also been a movement away from reciprocating engines used in refinery operations to electric motors and steam turbines, and occasionally, fossil-fueled combustion turbines (Reference 6). New sales for reciprocating engines will, therefore, be mostly for the replacement market, and the installed capacity of reciprocating engines for industrial applications will remain at essentially the same level in the 1978-1985 period. Projections of the 1985 installed capacity of reciprocating engines for industrial applications, assumed to be equal to the 1978 installed capacity, are presented in Table 6.

In terms of geographical distribution, the states with the highest installed capacity of utility gas turbines include New Jersey, Florida, New York, Pennsylvania, and Illinois. The states with the highest installed capacity of utility reciprocating engines include Kansas, Iowa, Missouri,

TABLE 6. CURRENT AND PROJECTED RECIPROCATING ENGINE INSTALLED CAPACITY FOR UTILITY AND INDUSTRIAL APPLICATIONS

Application Area	Installed Capacity 1978	Installed Capacity 1985
Utilities		
Diesel, dual fuel, and gas engine	5,300 MW	5,400 MW
Oil and gas transmission		
Diesel engine	780 MW	780 MW
Gas engine	9,380 MW	9,380 MW
Natural gas processing		
Gas engine	2,350 MW	2,350 MW
Oil and gas exploration		
Diesel engine	840 MW	840 MW
Gas engine	840 MW	840 MW
Crude oil and natural gas production		
Gas engine	4,000 MW	4,000 MW
Industrial processes		
Gas engine	940 MW	940 MW
On site power generation		
Gas engine	350 MW	350 MW
Total	24,780 MW	24,880 MW

Michigan, and Minnesota. In industrial applications, most of installed capacity for gas turbines and reciprocating engines is for oil and gas transmission, crude oil production, and natural gas production and processing. Industrial gas turbines and internal combustion engines are, therefore, mostly found in states having more mileage of oil and gas transmission pipelines and higher oil and gas production activities. For natural gas transmission, for example, the nine states of Louisiana, Texas, Kansas, Mississippi, Pennsylvania, Kentucky, Michigan, New Mexico and Tennessee account for approximately 65 percent of the installed reciprocating engine and gas turbine horsepower (Reference 11).

3.3 POPULATION CHARACTERISTICS

For utility gas turbines, FPC has published data on plant capacity, plant fuel use, number of units, size of each unit and the year of installation for each unit (References 12 and 13). Analysis of the FPC data shows that as of December 31, 1973, the average size for utility gas turbines (defined as total installed capacity divided by the total number of units) was approximately 29 MW. The same data also shows that 44 percent of the total number of utility gas turbine units were in the 15 to 20 MW size range. More recent data from Sawyer's Gas Turbine International indicates that the average size of utility gas turbines added after the end of 1973 is approximately 59 MW, with most of the new additions in the 45 to 70 MW size range (Reference 14). Thus, the trend is definitely toward the installation of large size turbines, and the current average size of utility gas turbines is approximately 31 MW. However, more than 40 percent of the total number of utility gas turbine units are still in the 15 to 20 MW size range. On this basis, utility gas turbines in the 15 to 70 MW size range should all be considered as representative. Analysis of the FPC age distribution data for utility gas turbines shows that as of December 31, 1973, the capacity average age was 2.7 years, and that 80 percent of the installed capacity was less than 5 years old. Combination of the FPC data with the new utility gas turbine installation data from Sawyer's Gas Turbine International then shows that as of December 31, 1976, the capacity average age for utility gas turbines is approximately 5 years, and that more than 80 percent of the installed capacity is less than 8 years old. Candidate test facilities selected for the utility gas turbine category should, therefore, be less than 8 years old.

Size and age distribution data for industrial gas turbines are not readily available. In Figure 2, the average size of gas turbines ordered for use by the oil and gas industry for extraction or transmission purposes is presented (Reference 3).

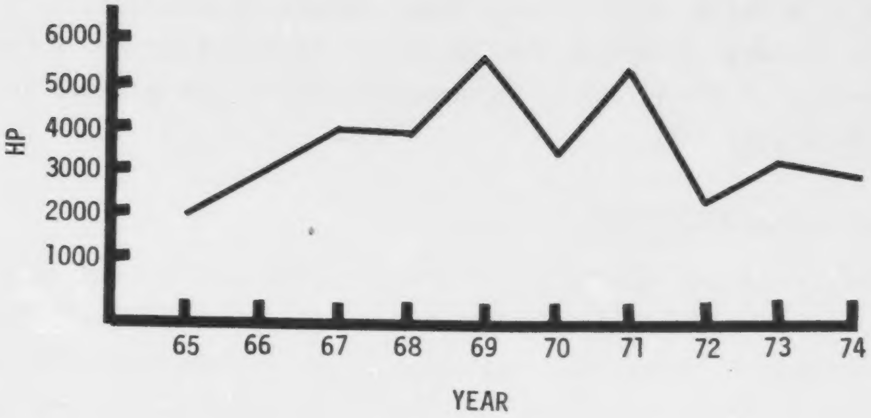

Figure 2. Average Size of Gas Turbines Ordered by the Oil and Gas Industry

From Figure 2, it is reasonable to assume that the average size unit in the oil and gas industry is approximately 3,000 HP or 2.2 MW. As the oil and gas industry represents the major industrial market for gas turbines, the average size unit for all industrial gas turbines would also be approximately 3,000 HP.

For reciprocating engines, it has been reported that the average size unit for electricity generation is approximately 2,500 HP or 1.9 MW, and the average size unit for oil and gas transmission is 2,000 HP or 1.5 MW (Reference 6). Recent data on the age distribution of utility and industrial reciprocating engines are not available. Based on an installed capacity of 5,300 MW and an estimated annual sales of 280 MW of reciprocating engines to the electric utility market, the average age of the utility reciprocating engine is approximately 10 years. The average age is estimated by assuming all annual sales are for the replacement market. Annual sales estimates are obtained from the same report (Reference 6). For industrial applications, with an installed capacity of 11,550 MW and an estimated annual sales of 570 MW of gas engines for gas transmission and processing, the average age of the industrial reciprocating engine is again approximately 10 years.

Air pollution control equipment is generally not installed on gas turbines or reciprocating engines, partially because particulate and SO_x emissions from these combustion sources are significantly lower than corresponding emissions from coal fired and resid oil fired boilers. There is, however, increasing recognition that NO_x emissions from gas turbines and NO_x, hydrocarbon, and CO emissions from reciprocating engines are major contributors to the nationwide emission burden. For gas turbines, water and steam injection have been accepted as valid techniques for NO_x control. In Table 7, a partial listing of the 74 turbine plants with water or steam injection for NO_x control is presented. In addition, to reduce visible emissions from oil-fueled turbines, fuel additives such as soluble compounds of barium, manqanese and iron are often employed. For oil-fueled reciprocating engines, additives to reduce visible emissions are not recommended by manufacturers because of concern over possible build-up problems at the cylinder ports. Fuel additives are, therefore, only infrequently used with oil-fueled reciprocating engines. Control of NO_x, CO and hydrocarbons through catalytic converters and reductions of CO and hydrocarbon emissions with afterburners are the only practical exhaust treatment methods for reciprocating engines. These control measures, however, have only been installed on a limited number of utility and industrial reciprocating engines.

TABLE 7. PARTIAL LISTING OF TURBINE INSTALLATIONS WITH WATER OR STEAM INJECTION FOR NO_x CONTROL (Reference 3)

Fluid Injected	Manufacturer	User	Location	Accumulated Hours		
				No. of Turbines	Hrs	Date
Water	Westinghouse	Florida Power & Light		4(1)	---	---
		Florida Power Corp.	Enterprise, Fla.	1	718	8-31-75
				1	614	8-31-75
		Kansas Power & Light	Abilene, Kansas	1	3194	8-31-75
		Jacksonville Elect.	Jacksonville, Fla.	1	857	
				1	1233	7-31-75
				1	1008	7-31-75
				1	779	7-31-75
		Kansai Electric Power	Osaka, Japan	NA	NA	NA(3)
		(2)Southern Calif. Edison	Daggett, Calif.	NA	NA	NA
	General Electric	San Diego Gas & Elect.	San Diego, Calif.	17	1000/unit	10-31-75
		San Diego Gas & Elect.	Naval Training Center	1	17,951	1-19-75
		Houston Power & Light	Houston, Texas	1	100	10-31-75
		Tucson Gas & Elect.	Tucson, Arizona	1	100	10-31-75
		Iowa Public Service	---	3	500	10-31-75
		Kansas Power & Light	---	3	3000 Total	10-31-75
	GE (On Order)	City of Jacksonville	Jacksonville, Fla.	1	---	---
		Florida Power Corp.	---	4	---	---
		Portland General Elect.	Portland, Oregon	6	---	---
		Arizona Power & Light	---	1	---	---
		(2)Southern Calif. Edison	Lucerne Valley, Calif.	---	---	---
		Ohio Edison	---	1	---	---

- Continued -

TABLE 7 (Continued)

Fluid Injected	Manufacturer	User	Location	Accumulated Hours		
				No. of Turbines	Hrs	Date
	Turbodyne	Houston Lighting & Power	Houston, Texas	not installed as of July 1976		
	Turbo Power & Marine	Burbank Public Service	Burbank, Calif.	1	NA	installed 4/74
		City of Glendale	Glendale, Calif.	1	NA	installed 10/73
		City of Pasadena	Pasadena, Calif.	2	NA	installed 5/74
		Southern Calif. Edison	Goleta, Calif.	2	27.3 each	1-13-76
Steam	Westinghouse	Union Carbide	Texas City, Texas	1	3000 plus(4)	
	General Electric	Union Carbide	Texas City, Texas	1	15 years - June 1975	
		Exxon	Baytown, Texas	7	48,000 as of 2-15-73 on 1 turbine	
	Turbodyne	Southern Calif. Edison		7	not installed yet	
	Turbo Power & Marine	City of Pasadena	Pasadena, Calif.	1	NA	NA
			Total installations:	58 minimum, water 16 steam		

Notes:
(1) Water injection system available but not being used.
(2) 19 gas turbines using water injection - total for both facilities.
(3) NA - not available.
(4) Unit was overhauled at 47,000 hrs. of operation with the last 3,000 using steam injection.

4. EMISSIONS

Air emissions from the flue gas stack are the only significant emissions from electricity generation and industrial gas turbines and reciprocating engines. Fugitive emissions from these internal combustion sources are negligible because the liquid fuels used have low volatility leading to minimum evaporative losses and the gaseous fuels are received continuously from a pipe rather than via a fuel storage tank and fuel pump. As a result of previous investigations (References 1, 3, 6, 11, 15, 16 and 17), NO_x emissions from oil- and gas-fueled turbines, NO_x, hydrocarbon, and CO emissions from oil- and gas-fueled reciprocating engines were identified as major contributors to the nationwide emissions burden. Emissions of these pollutants are discussed along with emissions of particulates, SO_x, trace elements, organic, and polycyclic organic matter (POM) from internal combustion sources in this section.

4.1 EVALUATION OF EXISTING EMISSIONS DATA

4.1.1 Criteria for Evaluating the Adequacy of Emissions Data

A major task in this program has been the identification of gaps and inadequacies in the existing emissions data base for combustion sources. The results of this effort determine the extent of the sampling and analysis program required to complete an adequate emissions assessment for each of the combustion-source types.

The criteria for assessing the adequacy of emissions data are developed by considering both the reliability of the data and the variability of the data. A detailed presentation of the procedures used to identify and evaluate emissions data is given in Appendix A. Briefly the general approach is to use a three-step process. In the first step the available data are screened for adequate definition of process and fuel parameters that may affect emissions as well as for validity and accuracy of sampling and analysis methods.

In the second step of the data evaluation process, emission data deemed acceptable in Step 1 are subjected to further engineering and statistical analysis to determine the internal consistency of the test results and the variability in emission factors. The third and final step in the process uses a method developed by Monsanto Research Corporation (MRC) which is based on both the potential environmental risks associated with the emission of each pollutant and the quality or variability of the data. The potential environmental risks associated with pollutant emissions are determined by the use of a source severity factor which is defined as the ratio of the calculated maximum ground level concentration of the pollutant species for an isolated typical source to the level at which a potential environmental hazard exists. If the variability of emission factor data is < 70 percent the data are deemed adequate. However, if the variability of the emissions data is > 70 percent the determination of data adequacy and the need for further measurement will be based on calculated severity factors for each pollutant. The data will be considered adequate if the upper bound of the source severity factor is $\leq$ 0.05.

4.1.2 Existing Emissions Data for Gas Turbines

The present study classifies gas turbines into the following categories:

1.3.30.0.0 Electricity Generation Internal Combustion Gas-Fueled Gas Turbine

1.3.22.0.0 Electricity Generation Internal Combustion Distillate Oil-Fueled Gas Turbine

2.3.30.0.0 Industrial Internal Combustion Gas-Fueled Gas Turbine

2.3.22.0.0 Industrial Internal Combustion Distillate Oil-Fueled Gas Turbine

As discussed in Section 3 of this report, on the basis of total installed horsepower, electricity generation is the predominant user of gas turbines. However, as the electric utility industry uses gas turbines primarily for peaking power rather than continuous power service, the total power generation and pollutant emissions from the utility sector are about the same order of magnitude as those from the industrial users.

Gas turbines for electric industry use range in power generation capacity from 14 to over 100 MW, with an average capacity of 30 MW. For industrial use, the typical capacity of gas turbines ranges from 10 to 20,000 HP (approximately 15 MW), with an average capacity of around 3,000 HP (2.2 MW). Thus the industrial gas turbines are generally of smaller capacity than the electric utility gas turbines, and the existing emissions data for these two user sectors will be evaluated separately.

Emissions Data Sources--

Review of the literature indicated that there are six primary sources of emissions data for gas turbines. The study conducted by McGowin contains mainly eight sets of NO_x emissions data for industrial gas turbines (Reference 15). The Standards Support and Environmental Impact Statement Document contains a tabulation of NO_x, CO and hydrocarbon emissions data for all four categories of gas turbines to be evaluated here (Reference 3). The Southwest Research Institute (SWRI) reports contain emissions data for industrial gas turbines, but the emissions data are restricted to NO_x, CO and hydrocarbon emissions from gas-fueled turbines (References 11 and 16). In another SWRI study, Hare and Springer compiled emissions data for electric utility gas turbines manufactured by General Electric, Turbo Power & Marine, and Westinghouse (Reference 17). Emissions data compiled include NO_x, CO, hydrocarbon, particulate, and SO_x emissions from both gas and distillate oil-fueled gas turbines. A comprehensive stack sampling program on fossil fuel burning gas turbines was conducted by Consolidated Edison during the May 1, 1973 to November 13, 1974 period (References 18 and 19). Emissions data collected include NO_x, CO, and hydrocarbon emissions from gas, kerosene, and No. 2 distillate oil-fueled gas turbines, and also particulate and trace element emissions for the oil-burning gas turbines. Trace elements for which emissions data have been reported include magnesium, lead, cadmium, beryllium, barium, vanadium and manganese. SO_x emissions reported were not measured but calculated based on the percent of sulfur in the fuel.

In addition to the primary reference sources cited above, Hurley and Hersh recently completed a study to characterize the effects of smoke and corrosion suppressant additives on the particulate and gaseous emissions from a utility distillate oil-fueled gas turbine (Reference 20). Exhaust samples from the turbine were analyzed for total particulate mass loading and composition, particulate size distribution, polycyclic organic matter (POM) and gaseous emissions including NO_x, CO, hydrocarbons, SO_2 and SO_3. The results of the investigation showed a reduction in total particulate loading when fuel additives of barium/manganese, organic manganese, iron or chromium are used, although particulate size distributions were not shifted significantly. Furthermore, the effects of fuel additives on gaseous emissions, including POM, were found to be insignificant. This is an important conclusion since fuel additives are commonly employed to suppress visible smoke emissions from distillate oil turbines, and it has been shown that there is no need to subclassify the gaseous emissions data on the basis of fuel additive introduction.

Industrial Gas and Distillate Oil-Fueled Gas Turbines--

The emissions data for industrial gas and distillate oil-fueled gas turbines, as compiled from the McGowin, SWRI and Standards Support and Environmental Impact reports, are summarized in Tables 8 and 9. For the SWRI emissions data for which accompanying humidity and load factor data are available, a humidity correction factor K has been applied to the NO_x values and load factor correction factors have been applied to the NO_x, CO and hydrocarbon values (Reference 11):

$$K = \frac{1}{1 - 0.003\ (H-44)}$$

where H is the humidity in grains H_2O/lb dry air

Load Factor = Operating Load/Rated Load

Emission at Rated Load = Emission at Operating Load × Correction Factor

Correction Factor for NO_x = $(\text{Load Factor})^{-0.5}$

Correction Factor for Hydrocarbons = $(\text{Load Factor})^2$

Correction Factor for CO = $(\text{Load Factor})^2$

As noted in Tables 8 and 9, the emissions data for industrial gas and distillate oil-fueled gas turbines are limited to NO_x, CO and hydrocarbon emissions. For these types of emissions, the existing data base is judged to be adequate as the variability $ts(\bar{x})/\bar{x}$ is less than 0.7 for all cases. For gas-fueled industrial turbines, SO_x emissions may be estimated from the sulfur content of natural gas, and particulate emissions may be assumed to be equal

TABLE 8. EXISTING EMISSIONS DATA FOR INDUSTRIAL GAS-FUELED GAS TURBINES UNDER BASE LOAD CONDITIONS

Turbine Model*	Base Load Rating (HP)	Emission Factor, ng/J			Reference
		NO_x	CO	HC	
DDA 404-3	270	213	79.5	--	3
GA 831-800	690	183	7.2	2.4	3
Solar Saturn	1,050	76	65.9	--	3
Solar T-1001	1,050	61	54.2	17.8	11,16
Unknown	1,100	66	--	--	15
Unknown	1,100	78	--	--	15
Solar Centaur	2,700	140	65.0	--	3
Unknown	3,350	159	30.7	5.7	3
DDA 501K-13	3,350	173	12.1	--	3
Unknown	6,200	223	--	--	15
Unknown	6,900	199	--	--	15
GE(I) M3912R	9,100	185	7.7	6.9	11,16
GE(I) Frame 3(S)	9,300	100	8.6	3.4	11,16
TPM GG 3C-1	10,500	112	65.0	20.8	11,16
GE(I) M3112R	11,100	176	3.9	6.9	11,16
TPM GG 3C-4	12,000	102	79.6	17.2	11,16
Unknown	13,900	40	81.1	--	3
Unknown	13,900	110	139.8	2.1	3
Unknown	13,950	133	--	--	15
Unknown	14,700	72	--	--	15
Unknown	14,700	125	--	--	15
Unknown	14,700	117	--	--	15
Unknown	20,000	139	31.0	2.9	11,16
Mean $\bar{x}$		130	48.8	8.6	
Standard Deviation of the Mean $s(\bar{x})$		11	10.0	2.3	
Variability $ts(\bar{x})/\bar{x}$		0.174	0.441	0.594	

* GE - General Electric

TPM - Turbo Power and Marine Systems

DDA - Detroit Diesel Allison

GA - Garrett AiResearch

TABLE 9. EXISTING EMISSIONS DATA FOR INDUSTRIAL DISTILLATE OIL-FUELED GAS TURBINES UNDER BASE LOAD CONDITIONS

Turbine Model*	Base Load Rating (HP)	Emission Factor, ng/J			Reference
		NO_x	CO	HC	
DDA 404-3	270	91	248	--	3
DDA 404-3	270	409	178	--	3
GA 831-800	690	258	16	--	3
GA 831-800	690	256	18	0.6	3
Solar Saturn	1,050	130	186	--	3
Unknown	1,350	113	40	5.7	3
Solar Centaur	2,700	160	142	--	3
Unknown	3,350	263	65	5.7	3
Unknown	3,350	254	30	5.1	3
DDA 501 K 15	3,350	223	62	--	3
Unknown	3,350	192	--	3.4	3
Unknown	13,900	89	160	--	3
Unknown	13,900	248	63	1.0	3
Mean $\bar{x}$		207	101	3.6	
Standard Deviation of the Mean $s(\bar{x})$		25	23	0.9	
Variability $ts(\bar{x})/\bar{x}$		0.264	0.493	0.680	

* DDA - Detroit Diesel Allison
GA - Garrett Airesearch

to those of gas-fueled utility turbines on an emission factor basis. Also, trace element emissions are not of concern because of the low trace element content of natural gas, and POM emissions are not of concern because of the paraffinic nature of natural gas and the large amount of excess air present in gas turbines. Other things being equal, the tendency for hydrocarbons to form POMs is:

Aromatics > Cycloolefins > Olefins > Paraffins

Natural gas contains predominantly saturated hydrocarbons which do not promote addition-type reactions between hydrocarbon species. Also, the absence of ring structure type compounds in natural gas means that there are no convenient building blocks for more condensed ring structures such as POMs. Based on the above considerations, it is concluded that the existing emissions data base is adequate for industrial gas-fueled gas turbines.

For industrial distillate oil-fueled gas turbines, the lack of particulate, SO_x, SO_3, particulate sulfate, trace element and organics emissions data leads to the conclusion that the existing emissions data base is inadequate. However, the emission factors for distillate oil-fueled gas turbines for industrial use and for electricity generation under base load conditions are expected to be similar for these types of emissions, and emissions data for utility distillate oil-fueled gas turbines may be used to estimate the emissions from industrial distillate oil-fueled gas turbines.

Electricity Generation Gas and Distillate Oil-Fueled Gas Turbines--

For the electric utility industry, gas turbines are used primarily for peaking power. An exception is combined cycle plants, which are generally designed for base load operation. Because the type and quantity of exhaust emissions from gas turbines are dependent on the operating load, it may be necessary to develop composite emission factors based on the operating cycle of gas turbines. In an analysis performed by Hare and Springer (Reference 17), the operating cycle for simple gas turbines was postulated to include 15 percent at zero load, 2 percent each at 25 percent, 50 percent and 75 percent load, 60 percent at 100 percent load, and 19 percent at 125 percent load, as depicted in Table 10. The composite emission factor was then calculated by summing the products of the emission factor and percent operating time spent at each load condition. The results of the analysis indicated that the composite emission factors for NO_x, particulate, and SO_x are almost equal to the unweighted emission factors at 100 percent rated power. For hydrocarbon and CO emissions, however, the composite emission factors were found to be 58 percent and 118 percent higher than the respective unweighted emission factors at 100 percent rated power, mainly because of the high hydrocarbon and CO emissions during gas turbine starts. On this basis, it is concluded that NO_x,

TABLE 10. POSTULATED OPERATING CYCLE FOR ELECTRIC UTILITY GAS TURBINES (Reference 17)

% of Rated Power	% Operating Time Spend At Condition	Time at Condition Based on 4.8 hr Day in Hours	in Minutes		Contribution to Load Factor at Condition
0	15	0.72	43		0.00 x 0.15 = 0.0
25	2	0.10	6		0.25 x 0.02 = 0.005
50	2	0.10	6		0.50 x 0.02 = 0.010
75	2	0.10	6		0.75 x 0.02 = 0.015
100 (base)	60	2.88	173		1.0 x 0.60 = 0.60
125 (peak)	19	0.91	55		1.25 x 0.19 = 0.238
		4.81	289	$\sum$ =	Load Factor = 0.868

particulate, and SO_x emissions data at base load conditions can be used to adequately characterize the emissions of these pollutants from gas turbines. The composite emission factors for hydrocarbon and CO emissions will be 1.58 and 2.18 times the corresponding unweighted emission factors at base load conditions. These composite factors can be used to estimate the total annual emissions from a simple cycle gas turbine:

Total annual emissions = Total installed base load rating x 8760
x capacity factor x average heat rate
x composite emission factor

$$\text{Capacity factor} = \frac{\text{Net generation (MW-hr)}}{\text{Installed base load rating (MW)} \times 8760 \text{ hr}}$$

Combined cycle plants are normally operated at base load conditions and therefor the composite emission factors and unweighted emission factors at based load are the same.

For electricity generation gas-fueled gas turbines, the existing emissions data for the criteria pollutants under base load conditions are presented in Table 11. As noted in Table 11, the existing data base for NO_x emissions is

TABLE 11. EXISTING EMISSIONS DATA FOR ELECTRICITY GENERATION GAS-FUELED GAS TURBINES UNDER BASE LOAD CONDITIONS

Turbine Model*	Base Load Rating (MW)	Emission Factor, ng/J					Reference
		NO_x	HC	CO	Part	SO_x	
TPM GG 4A-8	19.5	154	--	18.0	4.39	--	17
TPM FT4A	19.0	225	<7.7	13.5	7.32	2.22	17
TPM GG 4A-8	19.5	131	--	--	--	--	17
TPM FT4A-9DF	19.2	158	19.5	24.2	3.47	6.22	17
TPM FT4-9DF	19.0	214	57.1	124	--	--	18,19
GE MS 5001-LA	17.5	137	--	492	--	--	17
GE MS 5001-SC	Unkown	236	--	--	--	--	17
GE MS 7001-B	61.5	180	1.5	1.8	--	--	3
GE MS 5000-LA	14.6	135	2.1	15.0	--	--	18,19
GE MS 5000-N	17.5	169	4.3	8.6	--	--	18,19
GE MS 5000-LA	16.5	172	2.6	11.6	--	--	18,19
GE MS 5000-M	12.8	123	1.7	6.5	--	--	18,19
Unknown	13.0	178	4.0	44	--	--	3
Unknown	13.0	154	27.3	85	--	--	3
Unknown	25.0	159	1.3	3.9	--	--	21
Mean $\bar{x}$		168	15.0	29.7†	5.06	4.42	
Standard Deviation of the Mean $s(\bar{x})$		9	5.7	10.8	1.16	2.19	
Variability $ts(\bar{x})/\bar{x}$		0.112	0.849	0.803	0.987	6.32	
$\bar{x}_u = \bar{x} + ts(\bar{x})$		--	27.8	53.6	10.06	32.4	

* TPM - Turbo Power & Marine Systems
GE - General Electric

† The mean emission factor for CO was calculated after discarding the outlying data point 492 ng/J.

adequate. For hydrocarbon and CO emissions, the variability in emission factors is slightly greater than 0.7. However, it may be noted that more than 10 existing data points are available for both hydrocarbon and CO emissions, and the variability in emission factors is probably due to differences in equipment and operational characteristics. As such, additional data points would not necessarily reduce the variability in emission factors and the existing data base for hydrocarbon and CO emissions should be considered as adequate. For particulate emissions, the variability in emission factor is also slightly greater than 0.7. The mean particulate emission factor of 5.1 ng/J, however, is almost identical to the published AP-42 particulate emission factor of 5.7 ng/J for electricity generation gas-fueled gas turbines (Reference 23). Furthermore, as will be discussed later, the mean source severity factor for particulate emissions from electricity generation gas-fueled gas turbines is approximately 0.002, indicating that particulate emissions from gas-fueled turbines should not be an environmental problem. The existing data base for particulate emissions is, therefore, also considered to be adequate. For SO_x emissions, although only two existing data points are available and the variability in SO_x emissions is large, SO_x emissions may be estimated assuming an average natural gas sulfur content of 4,6000 $g/10^6\ m^3$. Also, as discussed in the case of industrial gas turbines, trace element and POM emissions are not of concern for gas-fueled gas turbines. Overall, the existing emissions data base is, therefore, adequate for electricity generation gas turbines.

For electricity generation distillate oil-fueled gas turbines, the existing emissions data for the criteria pollutants under base load conditions are presented in Table 12. The variability $ts(\bar{x})/\bar{x}$ in NO_x, hydrocarbon, CO, particulate and SO_x emissions for electricity generation distillate oil turbines is less than 0.7 for all cases, and the existing data base for these criteria pollutants is therefore considered to be adequate. In the Hurley and Hersh study, particulate size distributions for the base load operation of a Turbo Power and Marine FT 4C-1LF turbine were derived from impactor data (Reference 20). The turbine operation in the investigation included the introduction of optimum concentrations of manganese/barium, organic manganese, and iron based fuel additives. The data showed that on the mass basis, 50 percent of the particulates are less than 0.17 μm in size, and that approximately

TABLE 12. EXISTING EMISSIONS DATA FOR ELECTRICITY GENERATION DISTILLATE OIL-FUELED GAS TURBINES UNDER BASE LOAD CONDITIONS

Turbine Model*	Base Load Rating (MW)	Emission Factor, ng/J					Reference
		NO_x	HC	CO	Part	SO_x‡	
TPM GG 4A-8	19.5	200	40.0	--	15.5	--	17
TPM TP 4-2	43.2	361	--	--	--	--	17
TPM FT 4A-9DF	19.2	412	<9.5	<16.7	18.5	6.9	17
TPM GG 4A-8	19.5	277	<9.0	<15.8	29.0	13.7	17
TPM FT 4-9DF	20.1	379	0.9	32.6	16.7	8.6	18,19
TPM FT 4-9DF	18.0	332	4.8	51.1	--	8.7	18,19
TPM FT 4A-8LF	17.5	275	3.0	3.7	10.3	8.7	18,19
TPM FT 4C-1LF	20.0	225	2.3	26.9	6.7	103	20
GE MS 5001-LA	17.5	269	--	--	--	--	17
GE MS 5001-SC	Unknown	301	--	--	--	--	17
GE MS 7001-SC	Unknown	395	--	--	--	--	17
GE MS 7001 B	60.4	216	--	--	--	--	3
GE MS 5001-NP	23.5	285	--	9.1	--	--	3
GE MS 7001 C	67.4	296	--	2.2	--	--	3
GE MS 7001 B	50.0	210	--	--	--	--	22
GE MS 5000-LA	13.9	204	3.0	21.9	30.5	43.8	18,19
GE MS 5000 N	20.3	319	4.3	8.2	9.1	57.1	18,19
GE MS 5000-LA	15.6	270	3.0	10.3	14.0	44.2	18,19
GE MS 5000-M	12.2	221	9.0	19.3	16.3	66.2	18,19
W 1916	12.5	209	--	31.0	--	--	3
W 501-B4	78.9	419	--	20.0	--	--	3
W 501 D	87.8	643	--	--	--	--	3
W 251	19.5	368	2.9	13.3	12.5	64.0	18,19
W 191	10.0	207	3.4	28.4	7.0	66.6	18,19
Turbodyne 11C	51.7	536	--	30.8	--	--	3
Unknown	52.9	253	--	--	--	--	3

- Continued -

TABLE 12. (CONTINUED)

Mean $\bar{x}$	311	4.6[†]	20.1	15.5	41.0
Standard Deviation of the Mean $s(\bar{x})$	21	0.8	3.0	2.2	9.1
Variability $ts(\bar{x})/\bar{x}$	0.140	0.404	0.320	0.314	0.490

[*] TPM - Turbo Power & Marine Systems
GE - General Electric
W - Westinghouse

[†] The mean emission factor for HC was calculated after discarding the outlying data point 40 ng/J using the method of Dixon.

[‡] The SO_x emissions data for the Con Edison gas turbines were calculated based on the percent of sulfur in the fuel (Reference 19).

90 percent of the particulates are less than 1 μm in size. Additionally, it was shown from the results of a particle-by-particle X-ray analysis that all the particles which contained the additive base element fell in the upper end of the measured size range, with typical diameters on the order of 1 μm. In several previous investigations, particulate size distribution determinations by filtration, light and electron microscopy and impaction have also shown that particulate emissions from distillate oil turbines were submicron, and in general, below 0.5 μm in diameter (References 24, 25 and 26). Thus, all the studies conducted have indicated that at least 90 percent of the particulate emissions from distillate oil turbines are less than 1 μm in size, and additional particulate size determinations are not required.

For SO_3 emissions from distillate oil fueled gas turbines, Johnson reported that based on the test data available in 1973, an average of 3.66 percent of the sulfur present in the fuel is converted to SO_3 and the remainder is converted to SO_2 (Reference 27). More recently, the Hurley and Hersh study found that based on 13 data points on a utility turbine with various injection rates of three types of fuel additives, and using an absorption-titration method for the determination of sulfur oxides, an average of 3.96 percent of the sulfur present in the fuel was converted to SO_3 (Reference 20). The excellent agreement between the two sets of data points indicates that there is no need for additional SO_3 measurements. In the Hurley and Hersh investigation, it was also determined from the exhaust particulate studies that approximately

1 percent of the sulfur present in the fuel was converted to particulate sulfate. The particulate sulfate data reported included metallic sulfates and a small fraction of particle-absorbed SO_3.

Emissions data for trace elements are presented in Table 13, and indicate that of the trace elements naturally present in the fuel, lead and magnesium are emitted in the greatest concentrations. Manganese and barium are additives to the kerosene or No. 2 distillate oil to retard visible smoke emissions and are therefore also emitted in greater concentrations. Calculation of the variability $ts(\bar{x})/\bar{x}$ in trace element emissions show that the emissions data base is adequate for lead and beryllium. In addition, the ASTM gas turbine fuels committee has recently approved a revised set of trace element limits for gas turbine fuels (Reference 28). The limits for the critical trace elements, including vanadium, sodium and potassium, calcium, and lead are shown in Table 14. These trace element limits may be used to calculate the maximum emissions for these four trace elements from distillate oil turbines, as presented in Table 15. By comparison, the emission factors for lead and vandaium estimated from existing data are well within the limits of these maximum emissions. For trace element emissions for which variability data are available, the upper bound S_u for the mean severity factors have also been calculated from $\bar{x}_u = \bar{x} + ts(\bar{x})$. As will be presented later, the results of the source severity calculations show that among the trace element emissions, $S_u < 0.05$ for barium, cadmium, magnesium, manganese and vanadium. Of this basis, the existing emissions data base for these trace elements, as well as that for lead and beryllium, can be considered to be adequate.

For POM emissions from utility distillate oil turbines, the only available data are from the Hurley and Hersh study (Reference 20). Testing for POM was conducted under reduced load conditions (approximately 70 percent of base load) with fuel additive injection and also for baseline cases with no additive. The POM samples were obtained using a Battelle Tenax absorption system. The POM data presented in Table 16 show that the largest emissions to consistently appear were the anthracene/phenanthrene species, both of which are known to be noncarcinogenic. Benzo(a)pyrene, a known carcinogen, was found in only one of the tests. The data also showed the apparent catalytic effect of the iron additive on POM formation. The reliability of the Hurley and Hersh POM data,

TABLE 13. EXISTING TRACE ELEMENT EMISSIONS DATA FOR ELECTRICITY GENERATION DISTILLATE OIL TURBINES UNDER BASE LOAD CONDITIONS*

Turbine Model and Location	Fuel	Emission Factor, ng/J Mg	Pb	Cd	Be	Ba	V	Mn
Ravenswood #4 GE MS 5000-LA	Kerosene #2 Oil	3.86E-2 1.12E-1	4.47E-3 6.40E-3	1.03E-3 6.40E-4	1.33E-4 9.32E-5	1.48E-3 3.20E-3	1.48E-3 1.60E-3	1.62E-2 1.91E-2
Narrows 1-1 GE MS 5000 N	Kerosene	--	2.98E-3	4.73E-4	9.16E-6	1.24E-3	3.79E-4	3.55E-3
Astoria #12 W 251	#2 Oil	--	3.13E-3	4.60E-4	2.37E-5	2.49E-2	3.77E-3	5.76E-2
Astoria #7 W 191	#2 Oil	4.42E-2	1.03E-3	2.11E-5	2.11E-5	1.86E-2	2.07E-4	3.92E-2
Ravenswood #11 TPM FT 4-9DF	Kerosene	--	1.53E-2	2.26E-3	2.58E-4	2.59E-3	3.32E-3	1.93E-3
Ravenswood #5 GE MS 5000-LA	Kerosene #2 Oil	-- --	5.67E-3 2.75E-3	6.83E-4 1.02E-3	7.47E-5 1.02E-4	1.06E-3 1.22E-2	7.47E-4 2.04E-4	4.30E-3 1.02E-3
Ravenswood #7 GE MS 5000 M	#2 Oil	--	5.63E-3	5.07E-4	3.37E-4	5.07E-4	5.07E-4	3.07E-3
74th St #2 TPM FT 4A-8LF	Kerosene	--	2.16E-2	6.44E-3	2.98E-4	8.34E-4	2.98E-4	1.56E-3
Mean $\bar{x}$		6.48E-2	6.89E-3	1.36E-3	1.35E-4	6.65E-3	1.25E-3	1.48E-2
Standard Deviation of the Mean $s(\bar{x})$		2.35E-2	2.05E-3	5.97E-4	3.80E-5	2.76E-3	4.15E-4	6.10E-3
Variability $ts(\bar{x})/\bar{x}$		1.563	0.672	0.997	0.637	0.940	0.749	0.936
$\bar{x}_u = \bar{x} + ts(\bar{x})$		1.66E-1	1.15E-2	2.71E-3	2.21E-4	1.29E-2	2.19E-3	2.86E-2

*All the emissions data were obtained from Con Edison (Reference 19). Also magnesium and barium were added to the kerosene and No. 2 distillate oil to retard visible smoke emissions.

TABLE 14. ASTM-D-2880-76-TRACE METAL LIMITS FOR GAS TURBINE FUELS (Reference 28)

ASTM No.	Fuel Type	Impurity Content, ppm by Weight			
		Vanadium	Sodium & Potassium	Calcium	Lead
0	Naphtha	0.5	0.5	0.5	0.5
1	Kerosene	0.5	0.5	0.5	0.5
2	No. 2 Fuel Oil	0.5	0.5	0.5	0.5
3	Heavy Distillate	0.5	0.5	0.5	0.5

TABLE 15. MAXIMUM TRACE METAL EMISSIONS BASED ON ASTM-D-2880-76 GAS TURBINE FUEL LIMITS (Reference 28)

ASTM No.	Fuel Type	Emission Factor, ng/J			
		Vanadium	Sodium + Potassium	Calcium	Lead
0	Naphtha	0.112	0.112	0.112	0.112
1	Kerosene	0.112	0.112	0.112	0.112
2	No. 2 Fuel Oil	0.112	0.112	0.112	0.112
3	Heavy Distillate	0.112	0.112	0.112	0.112

however, is somewhat questionable, especially because the highest POM levels obtained were from an ambient air sample. The existing data base for POM and other organics emissions is therefore inadequate. The overall assessment of the existing emissions data for electricity generation distillate oil-fueled gas turbines is that the data base is inadequate because of the paucity of data for trace elements and organics emissions.

Source Severity--

The mean source severity factor is defined as the ratio of the calculated maximum ground level concentration of the pollutant species for an isolated

TABLE 16. POM EMISSIONS DATA FOR AN ELECTRICITY GENERATION DISTILLATE OIL-FUELED GAS TURBINE OPERATING AT 70 PERCENT LOAD (Reference 20)

POM Species	Emission Factor, pg/J No Additive	 Mn Additive	 Ba/Mn Additive	 Fe Additive
Anthracene/phenanthrene	1.53	1.36	1.37	2.36
Methyl anthracenes	0.95	0.84	0.66	1.03
Fluoranthene	0.23	0.24	0.25	0.52
Pyrene	0.10	0.14	0.12	0.46
Methyl fluoranthenes/pyrenes	ND	0.02	ND	0.06
Chrysene/benz(a) anthracene	0.06	ND	ND	0.18
Benzo fluoranthenes	ND	ND	ND	0.06
Benzo(a)pyrene	ND	ND	ND	0.03
Benzo(e)pyrene	ND	ND	ND	0.06
Perylene	ND	ND	ND	ND

ND - Not Detected. Detection limits were not specified in Reference 20.

typical source to the level at which a potential environmental hazard exists. Detailed methods for the calculation of source severity factors are described in Appendices A and B. In general, the potential environmental hazard level is taken to be the Threshold Limit Value (TLV) divided by 300 for non-criteria pollutants and the primary ambient air quality standard for the criteria pollutants. For pollutants for which no TLV is available, the Minimum Acute Toxicity Effluent (MATE) values based on health effects will be used in place of TLV's. The MATE concept was originally developed as a guide for environmentally safe emission concentrations from fossil energy processes, and MATE values for a large number of compounds have been recently developed under the direction of the U.S. Environmental Protection Agency (Reference 29). The MATE value based on health effects is usually assumed to equal the TLV whenever the TLV is available. The MATE values and TLV's are therefore equivalent, and it is reasonable to use MATE values as TLV's in the calculation of source severity factors whenever necessary.

In Tables 17 and 18, the mean emission factors and the mean source severity factors of air emissions from gas and distillate oil-fueled gas turbines are presented. Of the known emissions, NO_x has mean source severity factors >0.05 for all four gas turbine categories, indicating a potential environmental effect. In addition, SO_3 emissions from distillate oil-fueled gas turbines also have mean source severity factors >0.05, and should be considered as environmentally significant. The source severity factors for POM emissions have not been computed because reliable POM emissions data are not available from the existing data base.

The source severity concept has also been used in the evaluation of the adequacy of emissions data base. As discussed previously, the upper bound S_u for the mean source severity factor has been calculated for trace elements for which variability data are available. The results of these calculations show that among the trace element emissions from distillate oil-fueled gas turbines, $S_u < 0.05$ for barium, cadmium, magnesium, manganese, and vanadium. The existing emissions data base for these trace elements has therefore been considered adequate.

Status of Existing Emissions Data Base--

In summary, the evaluation of the adequacy of existing emissions data for gas turbines has led to the following conclusions:

- The existing emissions data base is adequate for industrial and electricity generation gas-fueled gas turbines.
- The existing data base for NO_x, HC and CO emissions is adequate for industrial distillate oil-fueled gas turbines. For other types of emissions, emissions data for electricity generation distillate oil-fueled gas turbines may be used to estimate the emissions from industrial distillate oil-fueled gas turbines.
- The existing data base for NO_x, HC, CO, particulate, SO_2 and SO_3 emissions is adequate for electricity generation distillate oil-fueled gas turbines. Among the trace elements, the existing data base for barium, beryllium, cadmium, lead, magnesium, manganese and vanadium emissions is adequate. However, the existing data base for other trace elements and organics emissions is inadequate for electricity generation distillate oil-fueled gas turbines.

TABLE 17. EMISSION FACTORS AND MEAN SOURCE SEVERITIES OF AIR EMISSIONS FROM GAS-FUELED GAS TURBINES

Parameter	Industrial Gas Turbine		Elec. Gen. Gas Turbine	
Average Unit Size	2.24 MW (3,000 HP)		30 MW	
Average Fuel Consumption	3.19×10^{14} J/year		4.28×10^{15} J/year	
Average Stack Height	24 m		159 m	
Pollutant	Emission Factor (ng/J)	Mean Severity S	Emission Factor (ng/J)	Mean Severity S
NO_x	130	0.5212	168	0.1711
HC	8.6	0.0246	23.8	0.0207
CO	48.8	0.0007	64.8	0.0003
Part	5.1	0.0062	5.1	0.0019
SO_x	0.26	<0.0001	0.26	<0.0001

(1) Average fuel consumption for industrial gas turbine was calculated assuming an average heat rate of 15,400 Btu/KW-hr and a capacity factor of 100%.

(2) Average fuel consumption for electricity generation gas turbine was calculated assuming an average heat rate of 15,400 Btu/KW-hr and a capacity factor of 100%.

(3) For industrial gas turbines, the NO_x, HC and CO emission factors were based on existing emissions data, the particulate emission factor was assumed to be the same as that for electricity generation gas turbines, and the SO_x emission factor was calculated assuming an average natural gas sulfur content of 4,600 g/10^6 m^3.

(4) For electricity generation gas turbines, the NO_x, HC, CO and particulate emission factors were all based on existing emissions data, whereas the SO_x emission factor was calculated assuming an average natural gas sulfur content of 4,600 g/10^6 m^3. Also, the HC and CO emissions factors are composite emission factors, which are equal to 1.58 and 2.18 times the corresponding unweighted emission factors at base load conditions.

TABLE 18. EMISSION FACTORS AND MEAN SOURCE SEVERITIES OF AIR EMISSIONS FROM DISTILLATE OIL-FUELED GAS TURBINES

Parameter	Industrial Distillate Oil Turbine			Elec. Gen. Distillate Oil Turbine		
Average Unit Size	2,238 MW (3,000 HP)			30 MW		
Average Fuel Consumption	3.19×10^{14} J/year			4.28×10^{15} J year		
Average Stack Height	24m			159 m		
Pollutant	Emission Factor (ng/J)	Mean Severity S	Upper Bound for Mean Severity S_u	Emission Factor (ng/J)	Mean Severity S	Upper Bound for Mean Severity S_u
NO_x	207	0.8309	-	311	0.3158	-
HC	3.6	0.0103	-	7.3	0.0063	-
CO	101	0.0014	-	43.8	0.0002	-
Part	15.5	0.0190	-	15.5	0.0058	-
SO_2	41.0	0.0360	-	41.0	0.0110	-
SO_3	1.9	0.2320	-	1.9	0.0704	-
As	8.94E-4	0.0002	-	8.94E-4	<0.0001	-
Ba	6.65E-3	0.0013	0.0025	6.65E-3	0.0004	0.0008
Be	1.35E-3	0.0065	0.0107	1.35E-3	0.0020	0.0033
Br	2.24E-4	<0.0001	-	2.24E-4	<0.0001	-
Cd	1.36E-3	0.0026	0.0052	1.36E-3	0.0008	0.0016
Cu	6.71E-4	0.0003	-	6.71E-4	<0.0001	-
Mg	6.48E-2	0.0010	0.0027	6.48E-2	0.0003	0.0008
Mn	1.48E-2	0.0003	0.0005	1.48E-2	<0.0001	0.0002
Pb	6.89E-3	0.0044	0.0074	6.89E-3	0.0014	0.0023
Sn	1.10E-2	0.0005	-	1.10E-2	0.0002	-
V	1.25E-3	0.0002	0.0004	1.25E-3	<0.0001	0.0001

(1) Average fuel consumption for industrial distillate oil turbine was calculated assuming an average heat rate of 15,400 Btu/KW-hr and a capacity factor of 100%

(2) Average fuel consumption for electricity generation distillate oil turbine was calculated assuming an average heat rate of 15,400 Btu/KW-hr and a capacity factor of 100%

(3) For industrial distillate oil turbines, the NO_x, HC and CO emission factors were based on existing emissions data, the particulate, SO_2, SO_3 and trace element emission factors were assumed to be the same as those for electricity generation distillate oil turbines.

(4) For electricity generation distillate oil turbines, the NO_x, HC, CO, particulate, SO_2 and SO_3 emission factors were all based on existing emissions data. Also, the HC and CO emission factors are composite emission factors, which are equal to 1.58 and 2.18 times the corresponding unweighted emission factors at base load conditions. Among the trace elements, the emission factors for Ba, Be, Cd, Mg, Mn, Pb and V were based on emissions data provided by Con Edison, whereas the emission factors for As, Br, Cu and Sn were obtained from the GCA report (Reference 1).

4.1.3 Existing Emissions Data for Reciprocating Engines

The present study classifies internal combustion engines into the following categories:

1.4.22.0.0	Electricity Generation Internal Combustion Distillate Oil Reciprocating Engine
1.4.30.0.0	Electricity Generation Internal Combustion Gas Reciprocating Engine
2.4.22.0.0	Industrial Internal Combustion Distillate Oil Reciprocating Engine
2.4.30.0.0	Industrial Internal Combustion Gas Reciprocating Engine

The largest engines in the United States are about 13,500 HP (10 MW). The average size internal combustion (IC) engine for electricity generation is approximately 2,500 HP (1.9 MW). For the industrial sector, the estimated average size of IC engines is 2,000 HP (1.5 MW). although the majority of the sales for other industrial uses are below 1,000 HP. Because of the considerable overlapping in size ranges for electricity generation and industrial IC engines, the existing emissions data for these two user sectors will be evaluated together.

Emissions Data Sources--

Four primary sources of emissions data for electricity generation/industrial IC engines have been identified. The Acurex report contains a tabulation of NO_x, CO and total hydrocarbon emissions source test data supplied by engine manufacturers (Reference 6). The McGowin report includes NO_x, CO and total hydrocarbon emissions data from literature sources, engine manufacturers, and industrial sources of field data (Reference 15). The Southwest Research Institute (SWRI) reports contain NO_x, CO and total hydrocarbon emissions data from testing at compressor stations of natural gas pipelines, but the emissions data are restricted to gas-fueled IC engines (References 11 and 16). In the SWRI study, analyses of the emissions data have indicated that there is no direct relationship between NO_x emissions (the pollutant of primary interest for IC engines) and the engine cycle configuration (2- or 4-stroke cycle), or aspiration (natural or turbocharged) or rated engine horsepower. Therefore, no subgrouping of emissions data is necessary.

Electricity Generation/Industrial Reciprocating Engines--

The emissions data compiled from the Acurex, McGowin, and SWRI reports are summarized in Tables 19 and 20*. For the SWRI NO_x emissions data for which accompanying humidity data are available, a humidity correction factor K has been applied to the NO_x values:

$$K = \frac{1}{1-0.003(H-75)}$$

where H is the humidity in grams H_2O/lb dry air (Reference 11).

As noted in Tables 19 and 20, the emissions data available are limited to NO_x, CO, and hydrocarbon emissions. For these types of emissions, the existing data base is judged to be adequate since the variability $ts(\bar{x})/\bar{x}$ is less than 0.7 for all cases. For gas engines, SO_x emissions are not of concern and may be estimated from the sulfur content of natural gas. As discussed in the case of gas-fueled turbines, particulate, trace elements and POM emissions from gas engines should be insignificant. Also, particulate emissions from gas engines may be assumed to be equal to particulate emissions from gas turbines on an emission factor basis. It, therefore, follows that the existing emissions data base is adequate for electricity generation/industrial internal combustion gas reciprocating engines.

For distillate oil engines, SO_x emissions may be estimated from the fuel sulfur content. Manufacturers of diesel engines currently recommend that users burn only fuels which contain less than 0.5 percent sulfur (Reference 6). This practice is suggested to minimize corrosion, but it also results in SO_x emission levels of less than 2 g/bhp-hr from most distillate oil engines, and an average SO_x emission level of 0.946 b/bhp-hr for these engines (Reference 1).

For SO_3 emissions from distillate oil-fueled reciprocating engines (diesel engines), Hunter and Engel recently reported measurements made by Goksoyr-Ross

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* Note that emission factors for gas and distillate oil engines are normally reported in units of g/bhp-hr.

TABLE 19. EXISTING EMISSIONS DATA FOR ELECTRICITY GENERATION/ INDUSTRIAL GAS-FUELED STATIONARY RECIPROCATING ENGINES UNDER BASE LOAD CONDITIONS

Engine Model*	HP	Emission Factor, g/bhp-hr			Reference
		NO_x	CO	HC	
CB GMV-10	1,350	25.69	0.80	3.5	11,16
CB GMW-8	2,050	10.66	0.53	5.6	
CB GMW-8	2,000	18.45	0.31	4.9	
CB GMWA-6	1,500	13.93	0.53	6.3	
CB GMWA-8	2,000	8.01	0.48	3.6	
CB GMWC-6	2,000	10.01	0.92	5.4	
CB GMWC-10	3,400	23.67	0.75	5.5	
CB LSV-16	4,400	10.11	1.31	6.2	
CB LSVA-16	4,400	8.59	4.11	1.4	
CB 10V-250	3,400	11.22	0.53	4.1	
CB 14V-250	4,800	16.26	0.90	4.7	
CB 16V-250	5,500	18.82	1.48	3.9	
CB GMVA-8	1,080	15.1	0.3	1.9	6
CB GMVH-8	1,600	13.42	0.2	1.45	
CB KSV-12	3,240	12.75	-	4.26	
CL BA-8	1,600	8.76	0.97	4.1	11,16
CL BA-8	1,760	10.87	2.90	7.6	
CL HBA-8T	2,050	4.72	2.23	8.3	
CL TCV-12	4,000	6.90	2.83	5.5	
CL TCV-16	5,500	6.08	1.52	3.8	
CL TCVC-16	8,000	10.61	3.58	5.0	
CL TLA-6	2,000	8.57	2.84	4.3	
CL TLA-6	2,100	8.61	2.20	4.3	
CL TLA-8	2,700	8.54	2.18	7.6	
IR KVG-8	800	13.25	0.62	1.3	11,16
IR 616-KVR	5,500	9.92	0.90	2.2	
IR 412-KVS	2,000	15.11	0.68	2.8	
IR 616-KVT	4,000	7.17	1.04	2.8	

- Continued -

TABLE 19 (Continued)

Engine Model*	HP	Emission Factor, g/bhp-hr			Reference
		NO_x	CO	HC	
IR 412-KVSR	2,400	17.5	0.6	1.2	6
WS 6G-510	400	17.8	0.40	0.28	6
WS 8G-825	800	17.7	1.68	0.8	
WS 8GT-825	1,100	22.1	0.59	6.87	
WS 6G-510	360	21.5	1.0	1.0	
Unknown	large	12.5	9.0	0.9	6
Unknown	large	13.5	15.0	1.0	
Unknown	large	12.5	7.0	1.5	
Unknown	large	12.4	10.7	1.5	
Unknown	large	14.0	16.0	1.0	
Unknown	large	7.8	29.0	1.0	
Unknown	1,600	20.13	0.17	1.58	15
Unknown	2,140	7.4	-	-	
Unknown	1,940	8.9	-	-	
Unknown	5,230	11.8	2.0	1.1	
Unknown	400	7.6	-	10.1	
Unknown	800	14.2	1.7	4.4	
Unknown	800	9.4	6.0	30.6	
Unknown	1,000	16.8	7.4	-	
Unknown	2,260	9.6	-	-	
Unknown	1,950	12.1	-	-	
Unknown	1,610	9.7	3.8	4.3	
Unknown	1,540	10.9	3.0	3.2	
Unknown	3,600	9.1	1.8	4.1	
Unknown	3,655	7.4	2.5	4.4	
Unknown	2,000	8.5	4.6	5.4	
Unknown	1,080	15.23	0.29	1.94	15
Unknown	1,350	10.0	-	-	
Unknown	1,600	4.6	-	5.0	
Unknown	400	7.6	-	10.1	
Unknown	2,200	17.9	-	17.0	

- Continued -

TABLE 19 (Continued)

Engine Model*	HP	Emission Factor, g/bhp-hr			Reference
		NO_x	CO	HC	
Unknown	1,950	14.1	-	-	15
Unknown	4,000	10.4	-	-	
Unknown	925	15.7	0.9	6.5	
Unknown	750	12.5	1.1	-	
Unknown	800	9.1	0.5	16.8	15
Unknown	1,170	14.4	1.3	2.5	
Unknown	500	10.2	3.2	0.8	
Unknown	800	10.9	-	2.0	
Unknown	1,320	13.0	5.6	1.8	
Mean $\bar{x}$ †		12.27	2.69	4.18	
Standard Deviation of Mean $s(\bar{x})$		0.55	0.46	0.44	
Variability $t\ s(\bar{x})/\bar{x}$		0.089	0.345	0.212	

*
CB - Copper Bessemer
CL - Dresser Clark
IR - Ingersoll Rand
WS - White Superior

† The mean emission factor for CO was computed after discarding the outlying data point 29.0 g CO/bhp-hr using the method of Dixon. The mean emission factor for hydrocarbons was computed after discarding the outlying data point 30.6 g HC/bhp-hr using the method of Dixon.

TABLE 20. EXISTING EMISSIONS DATA FOR ELECTRICITY GENERATION/ INDUSTRIAL DIESEL-FUELED STATIONARY RECIPROCATING ENGINES UNDER BASE LOAD CONDITIONS (Reference 6)

Engine Model*	HP	Emission Factor, g/bhp-hr		
		NO_x	CO	HC
EMD 12-645 E-3	2,475	12.51	1.19	0.38
CB KSV-12	4,300	10.99	3.85	0.13
Unknown	large	10.8	1.71	1.0
Unknown	large	11.4	-	0.44
Unknown	large	18.8	0.63	0.55
Unknown	large	16.3	0.53	0.18
Unknown	large	10.7	0.85	0.16
CB KSV-12-GDT	2,410	11.24	3.02	0.46
EMD 16-645 E	2,200	14.6	5.4	0.19
EMD 16-645 E-3	3,200	14.74	1.23	0.48
EMD 20-645 E-3	3,200	12.99	1.56	0.59
WS 40-8	620	8.70	8.50	0.25
Unknown	large	8.60	2.10	0.40
Unknown	large	7.40	0.8	0.50
Unknown	medium	6.60	1.9	0.60
Unknown	medium	4.60	4.1	0.60
Unknown	medium	4.0	1.6	0.30
Unknown	medium	5.5	1.3	0.20
Unknown	<500 hp	10.0	4.3	0.30
Unknown	large	8.2	1.0	0.30
EMD 8-645-E-3	1,650	12.88	0.93	0.42
EMD 12-645 E	1,650	14.74	4.14	0.49
EMD 8-645 E	1,100	17.07	2.20	0.37
Mean $\bar{x}$ †		11.02	2.11	0.40
Standard Deviation of Mean $s(\bar{x})$		0.83	0.31	0.04
Variability $t\ s(\bar{x})/\bar{x}$		0.156	0.310	0.210

* EMD - Electromotive Division (GM)
CB - Copper-Bessemer
WS - White-Superior

† The mean emission factor for CO was computed after discarding the outlying data point 8.5 g CO/bhp-hr using the method of Dixon.

and Shell-Emeryville wet chemical methods (Reference 30). Results from the nine test conditions indicated an increase of SO_3 level with increased SO_2 level. An average of 2.13 percent of the fuel sulfur was found to be converted to SO_3, with a calculated variability $ts(\bar{x})/\bar{x}$ of 0.59. As this is the only set of data available and only one diesel engine was tested, additional SO_3 emissions data are required.

For other types of pollutants, data on particulates, particulate sulfate, trace elements and organics emissions are not available. The lack of these emissions data leads to the conclusion that the existing emissions base is inadequate for electricity generation/industrial internal combustion distillate oil reciprocating engines.

Source Severity--

In Tables 21 and 22, the mean emission factors and the mean source severity factors of air emissions from gas and distillate oil engines are presented. Of the known emissions, NO_x and hydrocarbons have mean source severity factors >0.05, for all four reciprocating engine categories, indicating that these are the problem pollutants common to all reciprocating engines. In addition, particulate, SO_x and SO_3 emissions from distillate oil engines also have mean source severity >0.05, even though these emissions have been previously considered as relatively unimportant for distillate oil engines. The mean source severity factors for particulate emissions from distillate oil engines were calculated using the AP-42 emission factor for particulates, and the reliability of this AP-42 emission factor is unknown.

Status of Existing Emissions Data Base--

In summary, the evaluation of the adequacy of existing emissions data for reciprocating engines has led to the following conclusions:

- The existing emissions data base is adequate for electricity generation/industrial internal combustion gas reciprocating engines.
- The existing data base for NO_x, HC, CO, and SO_2 emissions is adequate for electricity generation/industrial distillate oil reciprocating engines. The existing data base for particulates, SO_3, particulate sulfate, trace elements and organics emissions is inadequate for these combustion categories.

TABLE 21. EMISSION FACTORS AND MEAN SOURCE SEVERITIES OF AIR EMISSIONS FROM RECIPROCATING GAS ENGINES

Parameter	Industrial Gas Engine			Elec. Gen. Gas Engine		
Average Unit Size	1.5 MW (2,000 HP)			1.9 MW (2,500 HP)		
Average Fuel Consumption	1.39×10^{14} J/year			1.73×10^{14} J/year		
Average Stack Height	16.9 m			16.9 m		
Pollutant	Emission Factor		Mean Severity S	Emission Factor		Mean Severity S
	g/bhp-hr	ng/J		g/bhp-hr	ng/J	
NO_x	12.27	1550	5.666	12.27	1550	7.083
HC	4.18	528	1.321	4.18	528	1.651
CO	2.69	340	0.0040	2.69	340	0.0051
Part	0.04	5.1	0.0055	0.04	5.1	0.0068
SO_x	0.002	0.26	0.0002	0.002	0.26	0.0002

(1) Average fuel consumption for gas engine was calculated assuming an average heat rate of 7,500 Btu/bhp-hr and a capacity factor of 100%.

(2) The NO_x, HC and CO emission factors were based on existing emissions data, the particulate emission factor was assumed to be the same as that for gas fueled turbines, and the SO_x emission factor was calculated assuming an average natural gas sulfur content of 4,600 g/10^6 m^3.

TABLE 22. EMISSION FACTORS AND MEAN SOURCE SEVERITIES OF AIR EMISSIONS FROM RECIPROCATING DISTILLATE OIL ENGINES

Parameter	Industrial Distillate Oil Engine			Elec. Gen. Distillate Oil Engine		
Average Unit Size	1.5 MW (2,000 HP)			1.9 MW (2,500 HP)		
Average Fuel Consumption	1.39×10^{14} J/year			1.73×10^{14} J/year		
Average Stack Height	16.9 m			16.9 m		
Pollutant	Emission Factor g/bhp-hr	Emission Factor ng/J	Mean Severity S	Emission Factor g/bhp-hr	Emission Factor ng/J	Mean Severity S
NO_x	11.02	1390	5.089	11.02	1390	6.361
HC	0.40	51	0.1264	0.40	51	0.1581
CO	2.11	266	0.0032	2.11	266	0.0040
Part	0.81	102	0.1103	0.81	102	0.1379
SO_x	0.95	120	0.0920	0.95	120	0.1150
SO_3	2.53E-2	3.19	0.3316	2.53E-2	3.19	0.4144
As	0.70E-5	0.89E-3	0.0002	0.70E-5	0.89E-3	0.0002
Br	0.18E-5	0.89E-3	<0.0001	0.18E-5	0.89E-3	0.0001
Cu	0.53E-5	0.67E-3	0.0003	0.53E-5	0.67E-3	0.0004
Mn	0.23E-4	2.89E-3	<0.0001	0.23E-4	2.89E-3	<0.0001
Sn	0.86E-4	1.09E-2	0.0005	0.86E-4	1.09E-2	0.0006

(1) Average fuel consumption for distillate oil engine was calculated assuming an average heat rate of 7,500 Btu/bhp-hr and a capacity factor of 100%.

(2) The NO_x, HC and CO emission factors were based on existing emissions data, the particulate emission factor was obtained from AP-42 (Reference 23), and the SO_x and trace element emission factors were based on the average sulfur and trace element content of distillate oil (Reference 1).

4.2 EMISSIONS DATA ACQUISITION

4.2.1 Selection of Test Facilities

Because gas turbines and reciprocating engines contribute significantly to the nationwide NO_x emissions burden, these combustion categories have been identified as major stationary sources of air pollution. In the evaluation of existing emissions data for these combustion sources, it has been determined that the existing emissions data base is adequate for electricity generation and industrial gas-fueled gas turbines and reciprocating engines, and inadequate for electricity generation and industrial oil-fueled gas turbines and reciprocating engines. Further, the inadequacy of the existing emissions data base for the oil fueled internal combustion sources is largely due to the paucity of data for trace element and organic emissions. The combination of significant air pollution impact and data inadequacy led to the decision of selecting five test sites each for electricity generation distillate oil turbines and for electricity generation distillate oil reciprocating engines in the first phase. For electricity generation gas-fueled gas turbines and gas reciprocating engines, it was decided to select one test site for each source category in the first phase to assure that previously unidentified pollutants are not being emitted in environmentally unacceptable quantities. Emissions data obtained from the electricity generation internal combustion sources will be extrapolated for use as estimates of emissions from the industrial internal combustion sources, especially because the size ranges for the electricity generation and industrial internal combustion sources often overlap and the equipment characteristics are similar.

The choice of specific sites was based on the representativeness of the sites as measured against the important characteristics of systems within each source category. As discussed in Section 3, candidate test facilities for electricity generation gas and distillate oil turbines should be in the 15 to 70 MW size range and less than 8 years old. Also, the use of fuel additives to reduce visible smoke emissions is quite prevalent for electricity generation distillate oil turbines, and some tests with fuel additives should be included. For electricity generation gas and distillate oil reciprocating engines, the average size unit has been estimated to be 1.9 MW (2,500 HP), with an average age of approximately 10 years. The engine model, rated capacity, age, and pollution control method for the eleven test sites selected are presented in Table 23. For gas and distillate oil turbines, the six test sites selected were all under 8 years old, in the 14.5 to 28 MW size range, and manufactured by Turbo Power and Marine Systems, one of the three major manufacturers of utility gas turbines. In addition, three of the distillate oil turbines selected used CI-2 (methyl cyclopentadienyl manganese tricarbonyl), a common organic manganese fuel additive. For distillate oil reciprocating engines, the five test sites selected all have electricity generation capacity of 2.5 MW, were either 1 year old or 8 years old, and all were manufactured by the Electromotive Division of General Motors, the principal manufacturer of utility diesel engines. An electricity generation gas reciprocating engine test site, however, could not be located during the course of this program. This is considered to have minimum impact because the existing emissions data base for this combustion source category has been judged to be adequate.

4.2.2 Field Testing

Field testing procedures were based on Level I environmental assessment methods. The Source Assessment Sampling System (SASS) was used to collect particulate, organic and trace metal samples. The SASS train (Figure 3) is a high volume (approximately 5 scfm) system designed to extract particulates and gases from the stack, separate particulates into four size fractions, trap organics in an adsorbent, and collect volatile trace metals in liquid solutions. A high volume system is required to collect adequate quantities of trace materials for subsequent laboratory analyses. The train is constructed such that all sample contacting surfaces are of Type 316 stainless steel, teflon or glass.

The internal combustion tests were carried out without the cyclones in the SASS train due to the low concentrations of particulates and their characteristic small particle diameters. The particulates were collected on Spectrograde$^{(R)}$ glass fiber filters in the heated oven. The sample stream was then cooled and the organic material collected by adsorption on XAD-2

TABLE 23. CHARACTERISTICS OF INTERNAL COMBUSTION SITES TESTED

Combustion Source Type	Site No.	Engine Model*	Rated Capacity		Age	Pollution Control Device
			Base Load	Peak Load		
Gas Turbine	#110	TPM FT 4A-11DF	20.6 MW	22.6 MW	5 Years	None
Distillate Oil Turbine	#111	TPM FT 4A-11DF	20.6 MW	22.6 MW	5 Years	CI-2 Fuel Additive
	#112	TPM GG 4C-1D-DF	28 MW	30 MW	4 Years	None
	#306	TPM FT 4A-8LF	14.5 MW	22 MW	8 Years	CI-2 Fuel Additive
	#307	TPM FT 4A-8LF	14.5 MW	22 MW	8 Years	CI-2 Fuel Additive
	#308	TPM FT 4A-11LF	20.2 MW	26 MW	5 Years	None
Distillate Oil Reciprocating Engine	#309	EMD 64-5E4	2.5 MW	2.75 MW	8 Years	None
	#310	EMD 64-5E4	2.5 MW	2.75 MW	8 Years	None
	#311	EMD 64-5E4	2.5 MW	2.75 MW	8 Years	None
	#312	EMD 654	2.5 MW	2.75 MW	1 Year	None
	#313	EMD 654	2.5 MW	2.75 MW	1 Year	None

* TPM - Turbo Power and Marine Systems
EMD - Electromotive Division of General Motors

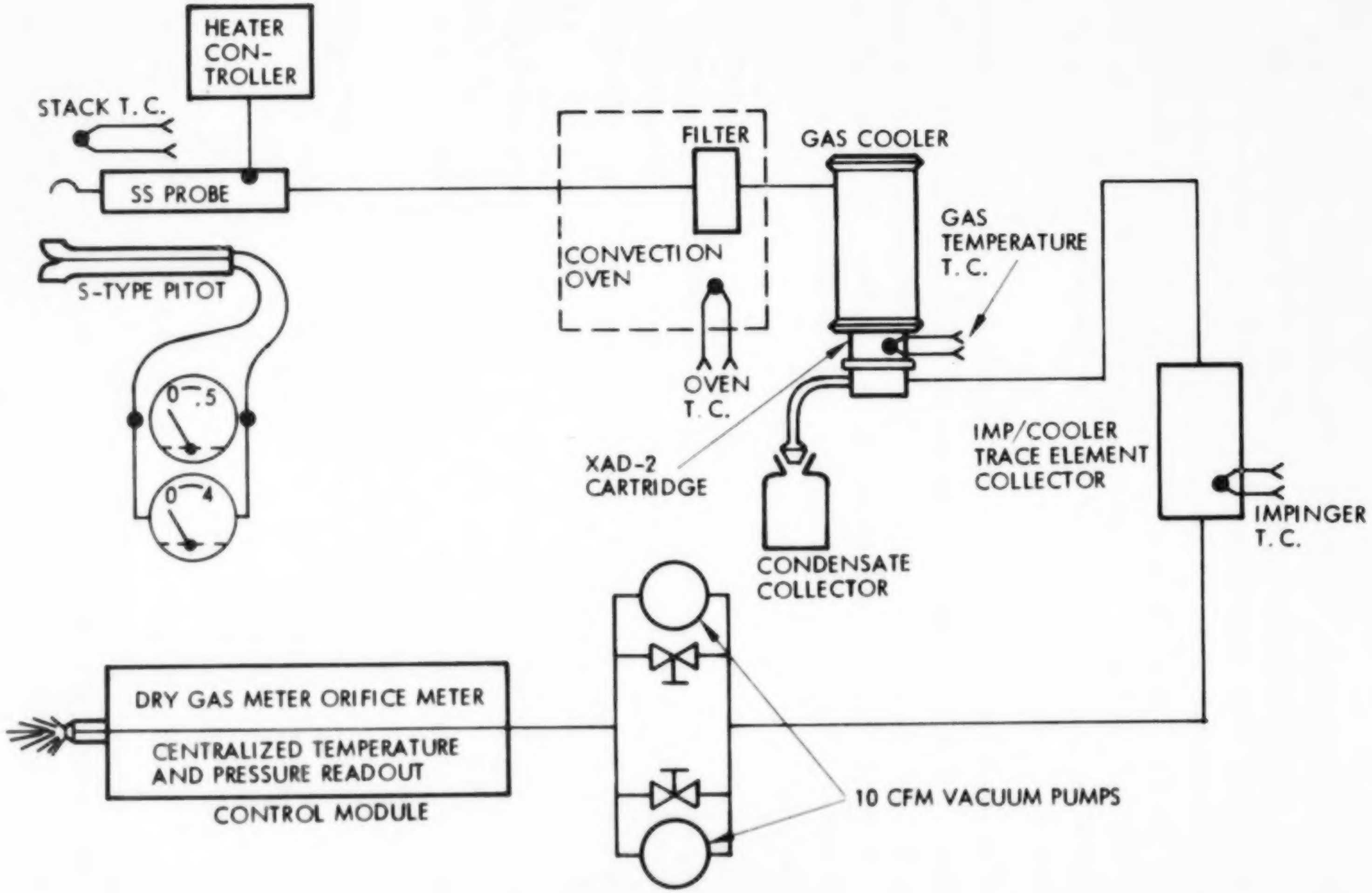

HEATER CON- TROLLER
STACK T. C.
SS PROBE
S-TYPE PITOT
0 .5
0 4
FILTER
CONVECTION OVEN
OVEN T. C.
GAS COOLER
GAS TEMPERATURE T. C.
XAD-2 CARTRIDGE
CONDENSATE COLLECTOR
IMP/COOLER TRACE ELEMENT COLLECTOR
IMPINGER T. C.
DRY GAS METER ORIFICE METER
CENTRALIZED TEMPERATURE AND PRESSURE READOUT
CONTROL MODULE
10 CFM VACUUM PUMPS

Figure 3. Schematic of Source Assessment Sampling System (SASS).

(a styrene, divinylbenzene copolymer). The gas then passed through an impinger containing hydrogen peroxide to collect oxidizable constituents. A second impinger with ammonium persulfate and silver nitrate and a third impinger with ammonium persulfate were used to collect volatile trace elements. At the time of testing, these were the methods outlined in the manual. The methods have since been changed requiring silver nitrate also in the third impinger. A fourth impinger containing silica gel was used to remove the remaining moisture.

A flue gas sample was collected for on-site analyses using a stainless steel probe, condenser, diaphragm pump and gas sampling bags. The gas in the bag was injected into the gas chromatrograph through a heated gas sampling valve. The resulting peaks were measured for retention times and areas and compared against a known series of C_1-C_6 standards for qualitative and quantitative analysis.

Low molecular weight hydrocarbons were measured in the field using a flame ionization detector gas chromatograph. The sample gas was compared to C_1-C_6 N-alkanes. CO_2, O_2, N_2 and CO were measured using a thermal conductivity detector gas chromatograph. Standard mixes of the gases were used for calibration.

Samples of the flue gas were obtained at a single traverse point approximating the average flow rate of the flue gas, as determined by a multi-point traverse. Sample time was from 4 to 6 hours as required to obtain a total sample volume of 30 cubic meters or greater.

Smoke spot numbers were determined using a Bachrach Smoke Spot Tester. Visible emissions (percent opacity) were determined by a trained observer.

Water, solid waste and fuel samples were collected according to Level I SASS procedures. Limited water analyses were carried out in the field as specified in the procedures manual.

Sample recovery was carried out in a clean environment according to Level I procedures. All sample containers were pre-cleaned and handled according to the Level I specifications.

Field tests were conducted at eleven internal combustion units in the first phase. Seven of the units had sampling ports located in the stack. The other four units were tested by use of a 3-foot SASS probe fitted with a vertical nozzle adaptor. The SASS probe was positioned approximately six inches above the stack at a point where the vertical adaptor sampled down into this stack at a traverse point of average stack velocity. A typical layout of an internal combustion unit is shown in Figure 4.

Test results from the first phase were evaluated to determine the need for and type of additional sampling and analysis. These evaluations led to the recommendation of additional tests to determine SO_3 and organic emissions from electricity generation distillate oil reciprocating engines. Level II tests were subsequently conducted at three of the diesel engine sites (Sites 309, 312, 313) previously tested. These were identified as Sites 309-2, 312-2 and 313-2.

At each of the Level II sites, the Goksoyr-Ross controlled condensation train was used for the measurement of oxidized sulfur emissions. In this approach, SO_3 is separated from the gas stream by cooling the flue gas below the dew point for SO_3 (H_2SO_4) but above the dew point of water. Particulate matter (including metallic sulfates) is removed by means of a heated quartz glass filter in a filter holder kept above 260°C (500°F). A condensation coil for SO_3 (H_2SO_4) collection is maintained at 60°C (140°F) by a water circulation bath. The SO_2 is removed in impingers filled with H_2O_2. A schematic diagram of the controlled condensation train is shown in Figure 5.

Level II organic samples were acquired using the SASS train without cyclones. Other changes made included the addition of acetone in the organic sample recovery washes and the omission of isopropyl alcohol from the impinger recovery washes.

4.2.3 Laboratory Analysis Procedures

The following sections present a detailed summary of the sample preparation and both inorganic and organic analysis procedures used for this part of

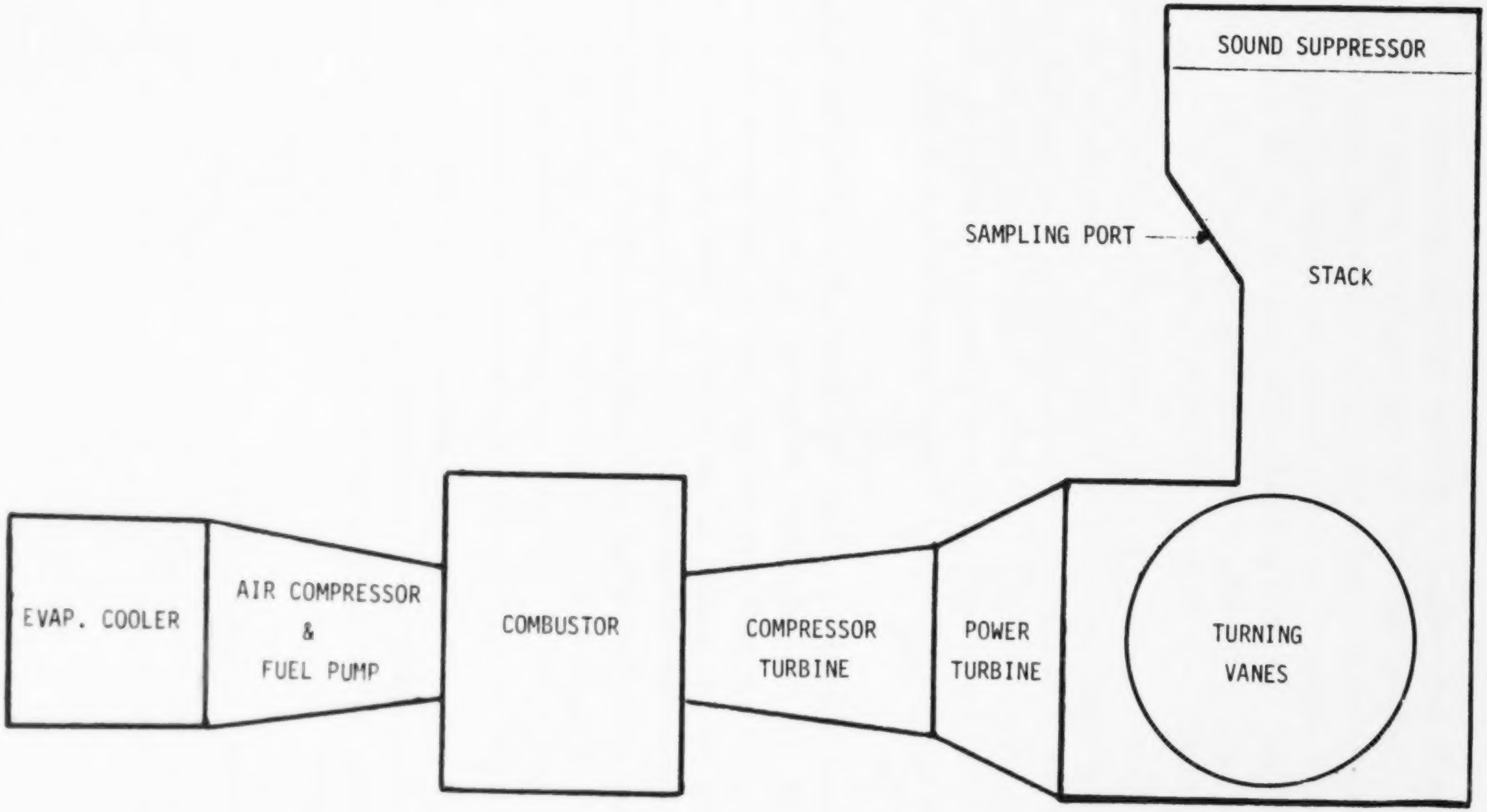

SOUND SUPPRESSOR
SAMPLING PORT
STACK
EVAP. COOLER
AIR COMPRESSOR
&
FUEL PUMP
COMBUSTOR
COMPRESSOR
TURBINE
POWER
TURBINE
TURNING
VANES

Figure 4. Typical Internal Combustion Unit

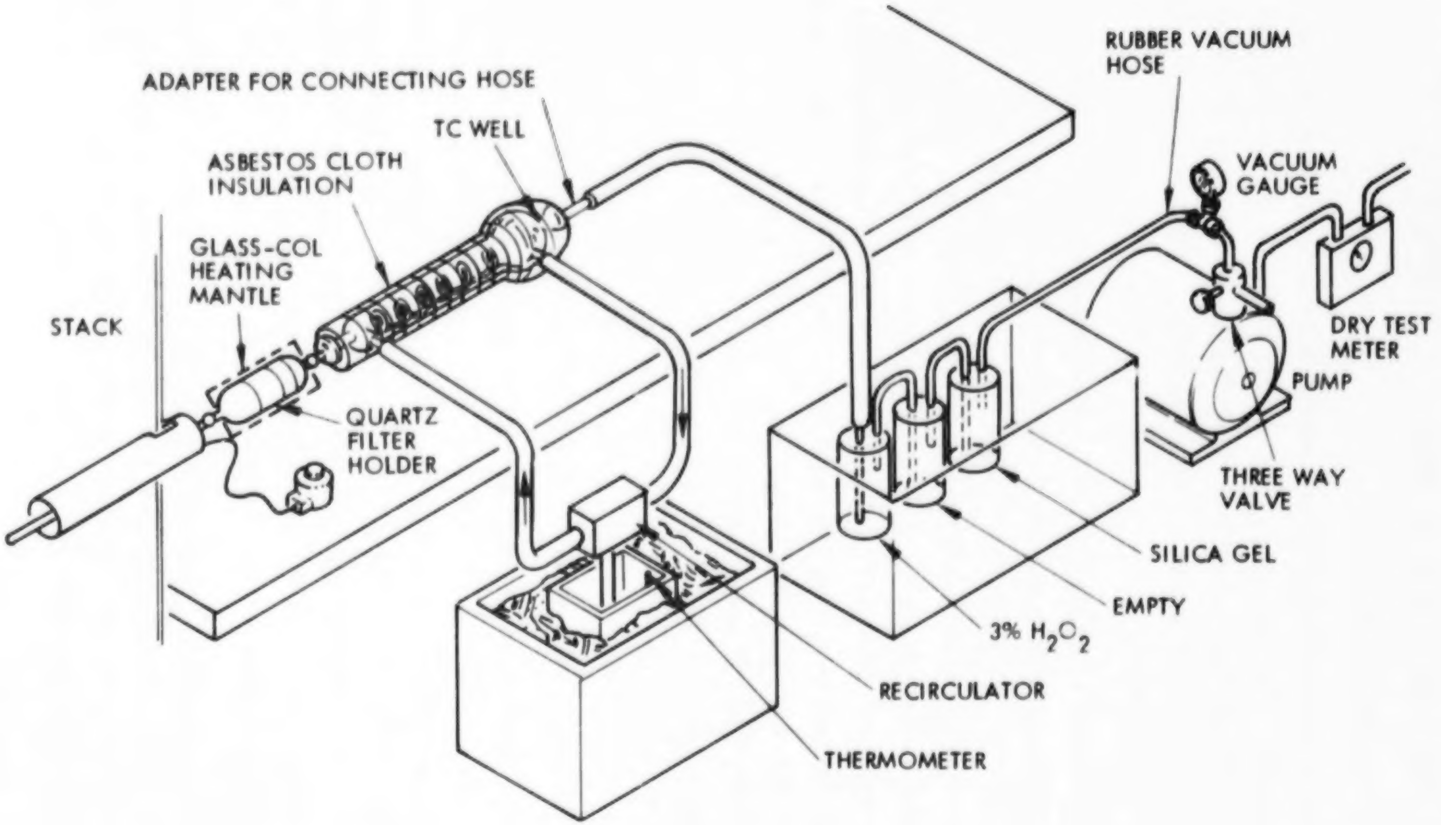

ADAPTER FOR CONNECTING HOSE
TC WELL
ASBESTOS CLOTH INSULATION
GLASS-COL HEATING MANTLE
STACK
QUARTZ FILTER HOLDER
RUBBER VACUUM HOSE
VACUUM GAUGE
DRY TEST METER
PUMP
THREE WAY VALVE
SILICA GEL
EMPTY
3% H_2O_2
RECIRCULATOR
THERMOMETER

Figure 5. Schematic of Controlled Condensation System.

the program. An exact written procedure for each disbursement and analytical operation is given in the program Methods and Procedures Manual (Reference 31) which has been published separately.

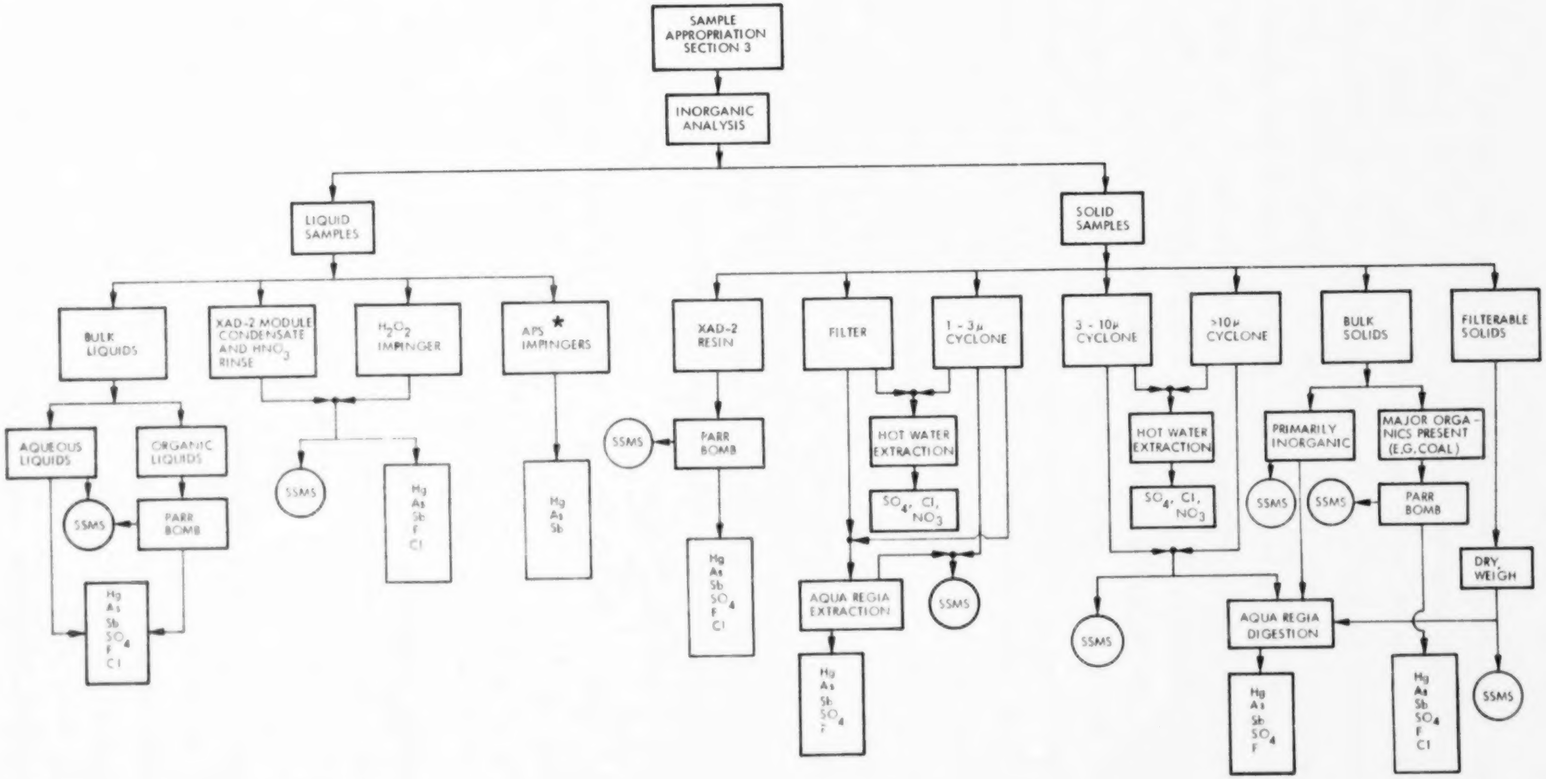
Inorganic Laboratory Analysis--

Level I inorganic analysis consisted of a Spark Source Mass Spectrometric (SSMS) elemental survey along with specific analyses for mercury, arsenic, antimony, and sulfate. Additional analyses for nitrate, fluoride, and chloride were also performed on selected samples. The analytical scheme followed is shown in Figure 6.

Both liquid and solid samples were received in the laboratory for analysis. Aqueous liquids required only minor preparations which are described in each analytical procedure (Reference 31). Organic materials, both liquid and solid, were combusted in a Parr oxygen bomb to destroy the organic matrix. Solids that were primarily inorganic (with the exception of glass fiber particulate filters) were analyzed directly by SSMS, but were digested with aqua regia for the other individual analyses. Particulate filters generally were acid digested for the SSMS analysis as well, because of the cohesion and sparking problems that are associated with having glass filters in the graphite electrodes. It is still preferable, however, to run all particulate samples for SSMS neat, and this was done whenever possible. Samples for chloride and nitrate analysis were prepared by extraction with hot water. These hot water extract solutions were also the preferred sample for sulfate analysis.

The prepared samples were aliquoted and disbursed by the Sample Bank Manager. Mercury was analyzed by a cold vapor technique and both arsenic and antimony were determined by hydride generation and Atomic Absorption Spectrometry (AAS) detection. The sulfate determination was a turbidimetric procedure and nitrate was measured colorimetrically after reaction with brucine. Specific ion electrodes were used to analyze both fluoride and chloride. These analyses are described further in the following paragraphs.

Spark Source Mass Spectrometry (SSMS) -- SSMS analysis was used to perform a semiquantitative elemental survey analysis on the Level I samples taken. The analysis was performed using a JEOL Analytical Instruments, Inc. Model JMS-01BM-2 Mass Spectrometer. The JMS-01BM-2 is a high resolution,


SAMPLE APPROPRIATION SECTION 3
INORGANIC ANALYSIS
LIQUID SAMPLES
SOLID SAMPLES
BULK LIQUIDS
XAD-2 MODULE CONDENSATE AND HNO3 RINSE
H2O2 IMPINGER
APS * IMPINGERS
XAD-2 RESIN
FILTER
1 - 3μ CYCLONE
3 - 10μ CYCLONE
>10μ CYCLONE
BULK SOLIDS
FILTERABLE SOLIDS
AQUEOUS LIQUIDS
ORGANIC LIQUIDS
SSMS
PARR BOMB
Hg As Sb SO4 F Cl
SSMS
Hg As Sb F Cl
Hg As Sb
SSMS
PARR BOMB
Hg As Sb SO4 F Cl
HOT WATER EXTRACTION
SO4, Cl, NO3
AQUA REGIA EXTRACTION
SSMS
Hg As Sb SO4 F
HOT WATER EXTRACTION
SO4, Cl, NO3
SSMS
PRIMARILY INORGANIC
MAJOR ORGANICS PRESENT (E.G. COAL)
SSMS
SSMS
PARR BOMB
DRY, WEIGH
AQUA REGIA DIGESTION
Hg As Sb SO4 F
Hg As Sb SO4 F Cl
SSMS

*APS - ammonium persulfate

Figure 6. Level I Inorganic Analysis Plan

double focusing mass spectrometer with Mattauch-Herzog ion optics. The instrument is specially designed to carry out high sensitivity trace element analysis with the aid of an RF spark ion source and photoplate detection. An aliquot of each sample to be analyzed is incorporated into two electrodes which are then mounted in the ion source of the mass spectrometer. These electrodes are "sparked" with a high voltage discharge which decomposes and ionizes the electrode material. Because of the high energy of the electrical discharge, most of the material is reduced to its elemental form. The ions formed are collected with focusing plates and subsequently measured in the mass spectrometer. Spark source mass spectrometry can be used to detect elemental concentrations down to 10^{-9} g(one nanogram). Although the sensitivity may vary somewhat from sample to sample, practically all elements (except H, C, N, O, and the inert gases) in the periodic table can be detected.

Interferences can result from the formation of multiple charged ions, ion clusters and molecular ions such as oxides, hydrides, hydroxides, and carbides. These interferences, coupled with the fact that the discharge conditions in the ion source are not easily reproduced, limit the accuracy of the technique. Spark source mass spectrometry, however, is very useful as a survey tool, and is capable of providing semiquantitative results (i.e., accurate to within a factor of 2 or 3).

Mercury - Cold Vapor -- The cold vapor mercury analysis is based on the reduction of mercury species in acid solution with stannous chloride and the subsequent sparging of elemental mercury, with nitrogen, through a quartz cell where its absorption at 253.7 nm is monitored.

Arsenic - Hydride Evolution -- The procedure entails the reduction and conversion of arsenic to its hydride in acid solution with either stannous chloride and metallic zinc or sodium borohydride ($NaBH_4$). The volatile hydride is swept from the reaction vessel, in a stream of argon, into an argon-hydrogen flame in an atomic absorption spectrometer. There, the hydride is decomposed and its concentration monitored at the resonance wavelength 193.7 nm. Some interferences with the Level I samples have been reported for this arsenic procedure. In particular, it has been found that excess hydrogen peroxide and nitric acid must be removed prior to the addition of either the zinc slurry or sodium borohydride used to generate the arsenic hydride.

Antimony - Hydride Evolution -- Antimony-containing compounds are decomposed by adding sulfuric and nitric acids and evaporating the sample to fumes of sulfur trioxide. The antimony liberated is subsequently reacted with potassium iodide and stannous chloride and finally with sodium borohydride to form stibine (SbH_3). The stibine is removed from solution by aeration and swept by a flow of nitrogen into a hydrogen diffusion flame in an atomic absorption spectrometer. The gas sample absorption is measured at 217.6 nm. Interferences in the flame are minimized because the stibine is freed from the original sample matrix.

Sulfate - Turbidimetric -- The basis of the analysis is the formation of a barium sulfate precipitate in a hydrochloric acid medium with barium chloride in such a manner as to form barium sulfate crystals of uniform size. The absorbance of the barium sulfate suspension was measured by a transmission photometer and the sulfate ion concentration determined by comparison of the reading with a standard curve.

Nitrate - Brucine Colorimetric -- Nitrate analysis was performed on hot water extracts of particulate samples from selected sites using the standard brucine nitrate colorimetric procedure. The reaction between nitrate and brucine sulfate produces a yellow color which can be used for the colorimetric estimation of nitrate. The intensity of the color is measured at 410 mμ. To each sample aliquot to be analyzed, sodium chloride and sulfuric acid solutions are first added. If any color or turbidity are present at this point, the absorbance is measured for a blank correction. The brucine-sulfanilic acid reagent is then added and the samples are kept in a bath of boiling water for 20 minutes. They are then cooled and their absorbance measured.

Fluoride - Specific Ion Electrode -- Fluoride was determined potentiometrically using a selective ion fluoride electrode in conuunction with a standard single junction sleeve-type reference electrode and a pH meter having an expanded millivolt scale. Sample pH was between 5 and 9. Polyvalent cations of Si^{+4}, Fe^{+3}, and Al^{+3} interfere by forming complexes with fluoride. The addition of a pH 5 total ionic strength adjustor buffer (TISAB II) containing a strong, chelating agent preferentially complexes aluminum (the most common interference), silicon, and iron and eliminates the pH problem.

The addition ot TISAB II also provides a high total ionic strength background to help mask the difference in total ionic strengths between samples and standards. However, the TISAB II cannot entirely compensate for this difference due to the very high and variable level of ionic strength in the Level I SASS samples. Thus a known addition technique is employed to eliminate the necessity of drawing different calibration curves for different types of samples.

Chloride - Specific Ion Electrode -- Chloride was determined potentiometrically using a solid state selective ion chloride electrode in conjunction with a double junction reference electrode and a pH meter having an expanded millivolt scale. The solid state electrode is used because it is not sensitive to the higher levels of nitrate, sulfate or bicarbonate which could be present in many of the samples. This method does require that the sample and standards have the same total ionic strength. A known addition technique is employed to eliminate the necessity of drawing different calibration curves for different types of samples because samples can have a very high and variable level total ionic strength.

Detection Limits--

The determination of a system's detection limits for different chemical species must include a discussion of three interrelated items. The first item is the determination of the analytical detection limit for each species as listed in the first part of Table 24. The second item is the determination of the species quantities needed in each type of SASS sample (particulate filters, XAD-2 module, impingers, etc.) to meet these analytical detection limits. The analytical detection limits together with the average volume, weight, or amount of the collected sample will yield through calculation the species quantity needed in each of the SASS train components in order to be detectable. This data when divided by the average volume of gas sampled, 30 m^3, yields the detectable species concentration in the gas stream ($\mu g/m^3$). This data appears in the second section of Table 24.

TABLE 24. ANALYTICAL SASS TRAIN DETECTION LIMITS

	Hg	As	Sb	$SO_4^=$	NO_3^-	F^-	Cl^-
I. Analytical Procedure Detection Limit (ppm)	0.0001	0.005	0.005	1.0	0.1	0.2	0.5
II. Average SASS Train Detection Limits (mg/m^3)							
a) Particulate on Filter	0.0008	0.08	0.07	62	1.6	3.1	9.1
b) XAD-2 Resin	0.013	1.3	1.2	1000	-	50	125
c) Composite*	0.005	0.5	0.4	390	-	20	50
d) Ammonium Persulfate impinger	0.003	0.3	0.2	-	-	-	-
III. Necessary Fuel Concentration to Meet Calculated SASS Train Detection Limits (ppm)							
a) Particulate on Filter	0.00006	0.003	0.003	0.6	0.06	0.01	0.03
b) XAD-2 Resin	0.001	0.07	0.07	14	1	0.3	0.7
c) Composite*	0.0004	0.02	0.02	4	.4	0.1	0.2
d) Ammonium Persulfate impinger	0.0003	0.01	0.01	-	-	-	-

* Composite - H_2O_2 impinger + condensate + module rinse.

The third item, shown in the last section of Table 24, is the determination of the species concentrations needed in the fuel to meet these gas stream detectable concentration values. This is derived by multiplying the volume of gas created by the combustion of one gram of fuel and the gas stream concentration values. This yields (in ppm) the species concentrations in the fuel required to produce detectable species quantities in the gas stream. The volume of gas per gram of fuel is obtained by using the Nernst equation and the stack emission formula (Appendix C) given below.

$$n_{FG} = \frac{F}{1 - 4.762\left(\frac{O_2}{100}\right)}$$

where:

n_{FG} = gram-moles of dry effluent/gram of fuel
F = gm-moles of dry effluent/gram of fuel under stoichiometric combustion (Appendix C)
O_2 = volumetric O_2 concentration, in percent, as determined from field gas analysis.

The value "n_{FG}" is then used in the Nernst equation to yield the volume of gas per gram of fuel, assuming 1 atm. and $20^\circ C$.

The values obtained for SASS train detection limits and corresponding fuel concentration levels necessary to meet these limits will vary for each site approximately ± one order of magnitude. This fluctuation is due to variations in field sample liquid and solid volumes and weights, and exit gas oxygen content.

Level I Organic Analysis Methodology--

An overview of the sources of the samples and the appropriate combinations of the samples for analysis is shown in Figure 7. The overview of the methodology and decision criteria used for the Level I organic sample preparation and analysis is shown in Figure 8.

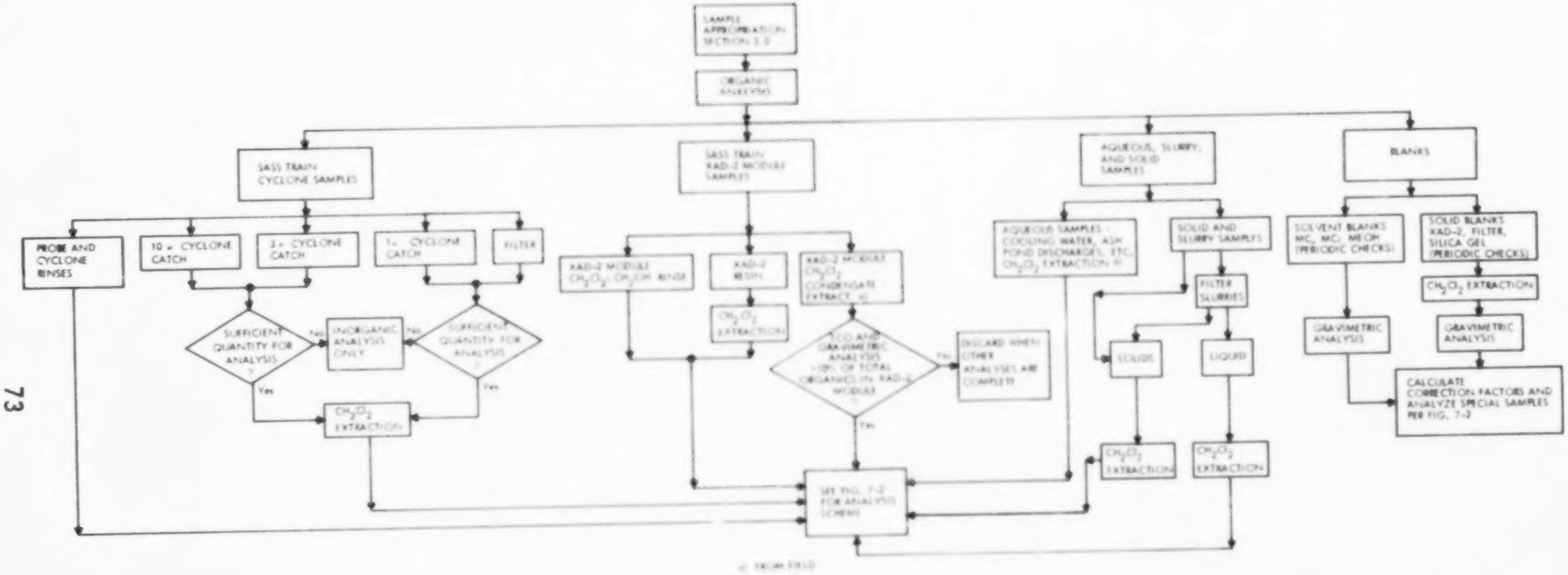

SAMPLE APPROPRIATION SECTION 3.0
ORGANIC ANALYSIS
SASS TRAIN CYCLONE SAMPLES
PROBE AND CYCLONE RINSES
10 μ CYCLONE CATCH
3 μ CYCLONE CATCH
1 μ CYCLONE CATCH
FILTER
SUFFICIENT QUANTITY FOR ANALYSIS ?
No
INORGANIC ANALYSIS ONLY
No
SUFFICIENT QUANTITY FOR ANALYSIS ?
Yes
Yes
CH$_2$Cl$_2$ EXTRACTION
SASS TRAIN XAD-2 MODULE SAMPLES
XAD-2 MODULE CH$_2$Cl$_2$/ CH$_3$OH RINSE
XAD-2 RESIN
CH$_2$Cl$_2$ EXTRACTION
XAD-2 MODULE CH$_2$Cl$_2$ CONDENSATE EXTRACT a)
TCO AND GRAVIMETRIC ANALYSIS >10% OF TOTAL ORGANICS IN XAD-2 MODULE ?
No
DISCARD WHEN OTHER ANALYSES ARE COMPLETE
Yes
SEE FIG. 7-2 FOR ANALYSIS SCHEME
a) FROM FIELD
AQUEOUS, SLURRY, AND SOLID SAMPLES
AQUEOUS SAMPLES - COOLING WATER, ASH POND DISCHARGES, ETC. CH$_2$Cl$_2$ EXTRACTION a)
SOLID AND SLURRY SAMPLES
FILTER SLURRIES
SOLIDS
LIQUID
CH$_2$Cl$_2$ EXTRACTION
CH$_2$Cl$_2$ EXTRACTION
BLANKS
SOLVENT BLANKS MC, MC: MEOH (PERIODIC CHECKS)
SOLID BLANKS XAD-2, FILTER, SILICA GEL (PERIODIC CHECKS)
CH$_2$Cl$_2$ EXTRACTION
GRAVIMETRIC ANALYSIS
GRAVIMETRIC ANALYSIS
CALCULATE CORRECTION FACTORS AND ANALYZE SPECIAL SAMPLES PER FIG. 7-2

Figure 7. Level I Organic Analysis Flow Chart

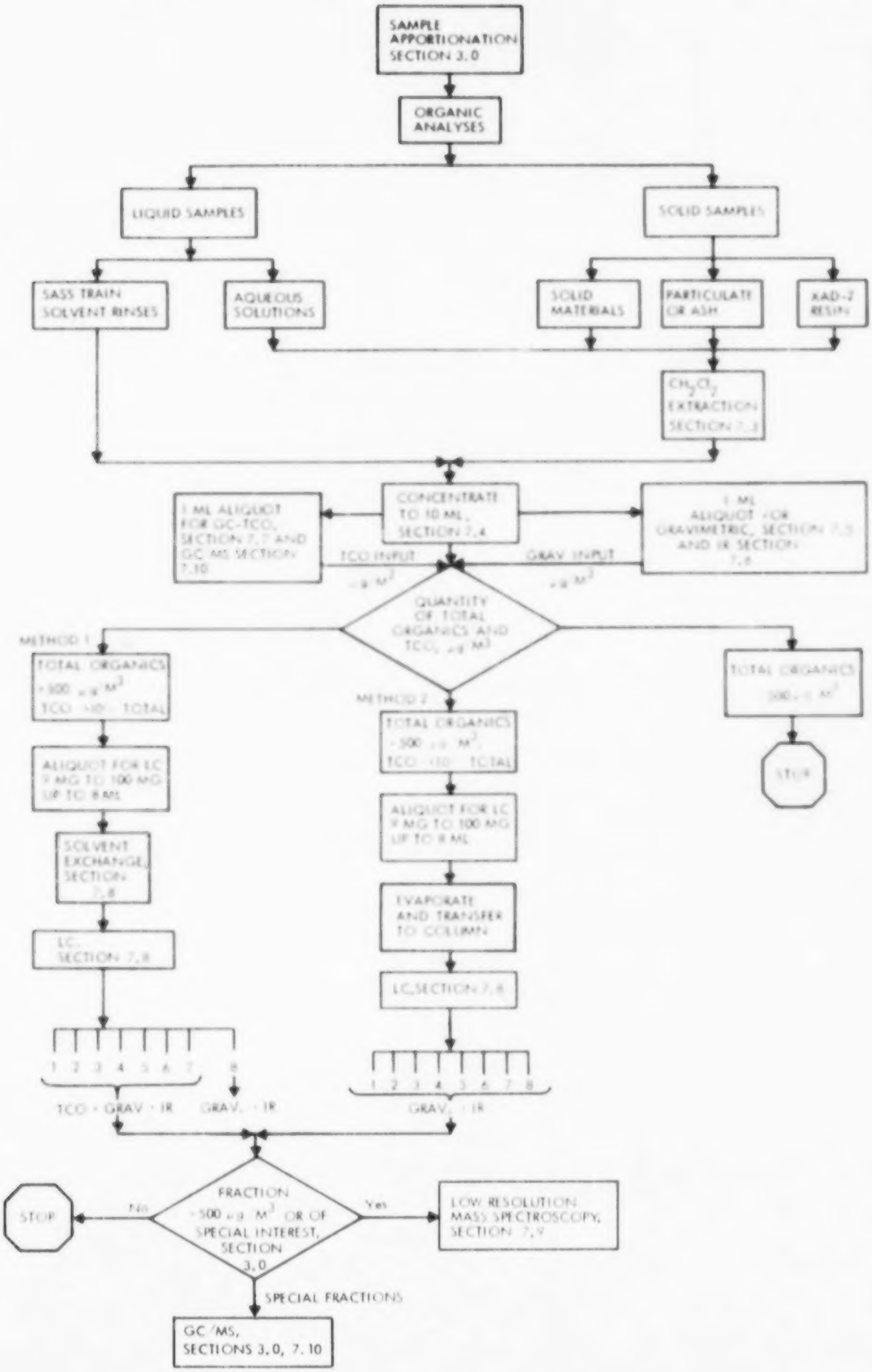

SAMPLE APPORTIONATION SECTION 3.0
ORGANIC ANALYSES
LIQUID SAMPLES
SOLID SAMPLES
SASS TRAIN SOLVENT RINSES
AQUEOUS SOLUTIONS
SOLID MATERIALS
PARTICULATE OR ASH
XAD-2 RESIN
CH_2Cl_2 EXTRACTION SECTION 7.3
CONCENTRATE TO 10 ML, SECTION 7.4
1 ML ALIQUOT FOR GC-TCO, SECTION 7.7 AND GC MS SECTION 7.10
1 ML ALIQUOT FOR GRAVIMETRIC, SECTION 7.5 AND IR SECTION 7.6
TCO INPUT
$\mu g/M^3$
GRAV INPUT
$\mu g/M^3$
QUANTITY OF TOTAL ORGANICS AND TCO, $\mu g/M^3$
METHOD 1
TOTAL ORGANICS >500 $\mu g/M^3$ TCO >10% TOTAL
ALIQUOT FOR LC 9 MG TO 100 MG UP TO 8 ML
SOLVENT EXCHANGE, SECTION 7.8
LC, SECTION 7.8
1 2 3 4 5 6 7 8
TCO + GRAV + IR
GRAV. + IR
METHOD 2
TOTAL ORGANICS >500 $\mu g/M^3$, TCO <10% TOTAL
ALIQUOT FOR LC 9 MG TO 100 MG UP TO 8 ML
EVAPORATE AND TRANSFER TO COLUMN
LC,SECTION 7.8
1 2 3 4 5 6 7 8
GRAV. + IR
TOTAL ORGANICS <500 $\mu g/M^3$
STOP
FRACTION >500 $\mu g/M^3$ OR OF SPECIAL INTEREST, SECTION 3.0
No
STOP
Yes
LOW RESOLUTION MASS SPECTROSCOPY, SECTION 7.9
SPECIAL FRACTIONS
GC/MS, SECTIONS 3.0, 7.10

Figure 8. Level I Organic Analysis Methodology

As indicated in these two figures, the extent of sample preparation required varied with sample type. Organic liquids did not need pretreatment. The majority of the samples, including SASS train components, aqueous solutions, bottom ashes, and other solids required an initial solvent extraction to separate the organic and inorganic portions of the samples before the analyses could be continued.

Both the extracts and the neat organic liquids were concentrated in a Kuderna-Danish evaporator to a 10 ml volume. Two 1 ml aliquots were then taken from each concentrate for the following analyses:

- Total chromatographable organic material (GC-TCO) and, should Level II efforts have been required, GC/MS analysis.
- Gravimetric determination of non-volatile organic material and an infrared analysis on the residue from the gravimetric determination.

The data provided by performing the TCO and the gravimetric analyses were used to make the decision as to the analysis path to be followed for all other determinations. The TCO analysis provided quantitative information on the bulk amount of semi-volatile organic material in the boiling range of the C_7 to C_{16} alkanes -- 90°C to 300°C. The gravimetric analysis provided quantitative results on the amount of non-volatile organics in the sample. These two values combined give an estimate of the total organic content of the sample. Whenever the total organic content of the sample was equivalent to a stack concentration of 500 $\mu g/m^3$ or less, the organic analysis was terminated. Whenever the value was greater than 500 $\mu g/m^3$ stack concentration, the direction of the analyses depended on the TCO results.

If the TCO was less than 10% of the total organic material, the analytical pathway labeled "Method 2" in Figure 8 was followed. A suitably sized sample aliquot was taken for liquid chromatographic fractionation, evaporated to dryness and transferred to an LC column. Each separated fraction was subsequently subjected to gravimetric and infrared analyses. If the TCO was greater than 10% of the total organics, an aliquot for LC was prepared by solvent exchange to preserve the volatile species. In this "Method 1" procedure, each fraction separated still underwent gravimetric and infrared analyses; however, in addition, the first seven LC fractions were first analyzed for TCO.

The GC-TCO analysis has been used to obtain information on the quantity of material boiling within discrete ranges corresponding to the boiling points of the n-alkanes C_7 through C_{16} as well as on the total amount of material in the overall n-alkane boiling range. Materials were classified solely on the basis of their retention time relative to the n-alkane, and were quantitated as n-alkanes. This means any compounds containing oxygen, nitrogen, sulfur or halogens would also be reported as alkanes.

The infrared analyses provided information on the major functional groups (i.e., chemical compound classes) present in a sample. Data obtained by the GC-TCO and IR analyses interrelated: many compounds detected in the GC analysis were too volatile to remain for IR analysis, and many compounds detected in the IR analysis had too low a volatility to be detected by the GC-TCO procedure. In a similar manner, the results of GC analyses of the LC fractions complemented the IR analyses of these samples.

The remaining paragraphs of this section briefly describe the analytical techniques used in conducting the Level I organic analysis.

Extraction of Samples for Organics--

Extraction of aqueous samples for organics -- Typical liquid samples that have been generated in this program include aqueous condensates, settling pond samples, and ambient water samples. These liquid extractions were performed with standard separatory funnels. The sample volume was measured and the sample was transferred to the separatory funnel. Whenever necessary, the pH of the sample was adjusted to neutral with either a saturated solution of sodium bicarbonate or ammonium chloride. The sample was extracted three times with a volume of high-purity methylene chloride equal to approximately 5 percent of the sample volume. The resulting extract was measured, dried with anhydrous sodium sulfate, and then concentrated to 10 ml.

Extraction of solid samples for organics -- Typical solid samples that have been generated in this program include cyclone catches, particulate filters, XAD-2 resin samples, bottom ashes, and electrostatic precipitator dusts. These extractions were performed in appropriately sized Soxhlet extractors. Each sample was placed or weighed into a glass thimble and extracted for 24 hours with Distilled-in-Glass$^{(R)}$ or Nanograde$^{(R)}$ purity methylene chloride. The resulting extracts were then concentrated.

Concentration of organic extracts -- Solvent extracts of solid and liquid samples and solvent rinses of sampling hardware were concentrated in Kuderna-Danish evaporators. Heat provided by a steam bath was sufficient to volatilize the solvents. All samples were concentrated to a volume between 5 ml and 10 ml and then, when cool, transferred to a volumetric flask and diluted to a final volume of 10 ml.

Gravimetric determinations for organics -- The weight of non-volatile organic species in samples for Level I organic analyses was determined on the concentrates obtained from the Kuderna-Danish concentrations of solvent extract and rinse samples. The samples were transferred to either small glass beakers (for LC fractions) or tared aluminum weighing dishes. The samples were then evaporated at ambient temperature to a constant weight. The dry samples were always stored in a desiccator. Weights of organic residues as small as 0.1 mg were measured.

Infrared analysis -- Infrared analysis was used to determine the functional groups present in an organic sample or LC fraction of a partitioned sample. The interpreted spectra provide information on functionality (e.g., carbonyl, aromatic hydrocarbon, alcohol, amine, aliphatic hydrocarbon, halogenated organic, etc.). Compound identification is possible only when that compound is known to be present as a dominant constituent in the sample.

The minimum sample amount required for this analysis has been 0.5 mg. A compound must be present in the sample at 5%-10% (w/w) at least for the characteristic functional groups of a compound to appear sufficiently strong for interpretive purposes. Organic solvents, water and some inorganic materials cause interferences. Water, in particular, can cause a decrease in the quality (i.e., resolution of a spectrum, sensitivity) of the analysis.

The initial organic sample or LC fraction, after evaporation, was either (1) taken up in a small amount of carbon tetrachloride or methylene chloride and transferred to a NaCl window, or (2) mixed with powdered KBr, ground to a fine consistency, and then pressed into a pellet. A grating IR spectrophotometer was used to scan the sample in the IR region from 2.5 to 15 microns.

C_7-C_{16} total chromatographable organic material analysis -- Gas chromatography is used to determine the quantity of lower boiling hydrocarbons (boiling points between 90°C and 300°C) in the concentrates of all neat organic liquids, organic extracts and LC fractions 1 through 7 (when LC Method 1 is used) encountered in Level I environmental sample analysis. Data were used to first determine the total quantity of the lower boiling hydrocarbons in the sample. Whenever the total of C_7-C_{16} hydrocarbons exceeded 75 μgm^3, the chromatographic results were reported as quantities in each of the C_7-C_{16} boiling point ranges rather than as a total.

The extent of compound identification is limited to representing all materials as normal alkanes based upon comparison of boiling points. Also, the analysis is semiquantitative because calibrations are prepared using only one hydrocarbon, n-decane. The differences in instrument response, or sensitivity, to other alkanes are well within the desired accuracy limits for Level I analysis and are not taken into consideration in data interpretation.

Liquid chromatographic separations -- This procedure is designed to give a separation of a sample into eight reasonably distinct classes of compounds and is applied to Level I analyses of SASS train samples which contain a minimum of 15 mg of non-volatile organics. Sample weights from bulk liquids and solids were evaluated on a case-by-case basis. A sample weighing from 9 mg to 100 mg was placed on a silica gel liquid chromatographic column. A series of eight eluents were employed to separate the sample into nominally eight distinct classes of compounds for further analyses.

The use of HCl in the final eluent results in a partial degradation of the column material. Thus, the eighth fraction has silica contaminants present in variable amounts. Filtration was attempted to separate silica gel from the organics, but silica was still often observed, particularly in infrared spectra.

As indicated in Figure 8, two distinct analytical procedures can be used in the performance of LC fractionations and subsequent analyses. The selection of the pathway "Method 1" or "Method 2" was based on the results of gravimetric and TCO determinations on the concentrated organic sample. For a LC separation to be required, the total organic content of the total, original sample must exceed 500 $\mu g/m^3$. Method 2 is used whenever the volatile hydrocarbon content determined by the TCO analysis is low -- less than 10% of the total. Method 1 is used whenever the volatile material content is in excess of 10% of the total.

The first difference between Method 1 and Method 2 is in the method of preparing the sample for introduction onto the LC column. In Method 2, where there are few volatile substances, a simple, direct solvent evaporation step is sufficient. In Method 1, however, care must be taken to preserve the lower boiling components through the LC separation and subsequent analyses. Therefore, a solvent exchange step has been incorporated to transfer the sample from methylene chloride to the non-polar solvent hexane. In addition, whenever Method 1 was used, a TCO analysis was performed on the first seven fractions for information on the mass and types of volatile compounds present in each fraction. These data supplemented the gravimetric and infrared analyses which were performed on all fractions.

Low resolution mass spectrometric analysis -- This procedure is a survey analysis used to determine compound types in an organic sample or in an LC fraction of a sample. The analyst is specifically searching for hazardous compounds or compounds which may be generally considered toxic, e.g., aromatic hydrocarbons and chlorinated organics. Analysis using different sample ionizing parameters results in molecular weight data, which, combined with IR and sample source data, can provide specific compound identifications on a "most probable" basis.

The mass spectrometer (MS) used in this procedure has sufficient sensitivity such that 1 nanogram or less presented to the ionizing chamber results in a full spectrum with a signal ratio of 10:1. A dynamic range of 250,000 is achievable. The detection limit for a specific compound related to the size of an air sample or liquid sample varies widely depending on the types and quantities of the species in the mixture. This is because of interfering effects in the spectrum caused by multiple compounds. The impact of this interference is reduced by lowering the ionization voltage to produce spectra containing relatively more intense molecular ions.

Solid samples are placed in a sample cup or capillary for introduction via the direct insertion probe. More volatile samples are weighed into a cuvette for introduction through a batch or liquid inlet system. The probe or cuvette is temperature programmed from ambient temperature to 300°C. Periodic MS scans are taken with a 70 eV ionizing voltage as the sample is volatilized during the program. A lower ionizing voltage range (10-15 eV) can be used at the discretion of the operator if the 70 eV data are complex. Spectra are interpreted using reference compound spectral libraries, IR data, and other chemical information available on the sample. The results of LRMS analysis give qualitative information on compound types, homologous series and, in some cases, identification of specific compounds. This information is then used to assess the hazardous nature of the sample.

Polycyclic organic compound analysis by gas chromatography/mass spectrometry -- This is a combined gas chromatography/mass spectrometry (GC/MS) method for qualitative and quantitative polycyclic organic material (POM) determinations. Microliter quantities of concentrated sample extracts derived from the sampling activity are used for this analysis.

Microliter sized samples are injected onto a gas chromatographic column and are separated by the differences in the retention characteristics between the sample components and the column material. As the components elute from the column, they are transported via an instrument interface to the mass spectrometer (MS), which is being operated in a Total Ion Monitoring (TIM) mode.

In the MS, the various compounds are ionized, and all ion fragments in the mass range of 40 to 400 AMU are monitored. The resulting mass spectra are stored by the computerized data system. All compounds eluting from the GC in detectable quantities could be identified, including aromatic compounds containing heteroatoms, depending upon the desired scope of the analysis. At this time, the computer is used to search the stored spectra for the specific mass fragments shown in Table 25.

The spectra of POM's are quite distinctive because they yield very strong molecular ions with little fragmentation. Using molecular ions to find POM's in a mixture involves reconstructing the GC trace from the stored data using only a single mass to charge (m/e) value. Any inflection in this mass chromatogram indicates the possibility of a POM of that molecular weight. The spectrum is then displayed and the operator judges if the spectrum is consistent with a POM. The GC retention time, as well as the spectrum, is used to make this identification although it is often difficult to confirm which isomer is causing a peak without standards for the specific material.

Using this technique, a large number of POM's can be screened in a short period of time and good identification of POM type is possible. More time is required for exact identification. Table 26 lists POM's which are sought in all samples; any POM with a molecular weight on this list will be determined. If other POM's with different molecular weights are desired, all that is needed for their identification is the molecular weight and a relative retention time or a standard. During the search of the data for POM compounds, non-POM compounds may interfere especially if they coelute with a POM. Computer data interaction techniques, such as ion mapping, keep these interferences to a minimum. If a POM is confirmed, the peak is quantitated using an internal standardization method.

The GC/MS sensitivity varies with several parameters including the type of compound, instrument internal cleanliness, resolution of closely eluting peaks, etc. Under "everyday" operating conditions 20 nanograms (ng) eluting in a peak about 5 seconds wide yields an MS signal with a usable signal to noise ratio. Typically, this represents at least 100 μg of any single POM compound in a concentrated extract of a sample.

TABLE 25. MASS TO CHARGE VALUES (m/e)s MONITORED*

128	180	242
154	184	252
162†	192	256
166	202	278
178	216	300
179	228	302

*Mass to charge values have units in (gm/gm mole)/(electron/molecule).

†Internal Standard Chloronapathalene.

TABLE 26. MINIMUM LIST OF POM's MONITORED

Compound Name	Molecular Weight	Mate Value, Air, μg/m^3
Naphthalene	128	5.0×10^4
Biphenyl	154	1.0×10^3
Fluorene	166	1.4×10^4
9,10 Dihydro-phenanthrene	180	N
9,10-Dihydro-anthracene	180	N
2-Methyl-fluorene	180	N
1-Methyl-fluorene	180	N
9-Methyl-fluorene	180	N
Phenanthrene	178	1.59×10^3
Anthracene	178	5.6×10^4
Benzoquinoline	179	N
Acridine	179	9.0×10^4
3-Methyl-phenanthrene	192	3.0×10^4
2-Methyl-phenanthrene	192	3.0×10^4
2-Methyl-anthracene	192	3.0×10^4
Fluoranthene	202	9.0×10^4
Pyrene	202	2.3×10^5
Benzo[a]fluorene or 1,2-benzofluorene	216	N
Benzo[b]fluorene or 2,3-benzofluorene	216	N
Benzo[c]fluorene or 3,4-benzofluorene	216	N
2-Methyl-fluoranthene	216	N
4-Methyl-pyrene	216	N
3-Methyl-pyrene	216	N
1-Methyl-pyrene	216	N
Benzo[c]phenanthrene	228	2.73×10^4
Benzo[ghi]fluoranthene	228	N
Benzo[a]anthracene	228	4.5×10^1
Chrysene	228	2.2×10^3
Triphenylene (9,10 Benzo phenanthrene)	228	N

(Continued)

TABLE 26. (Continued)

Compound Name	Molecular Weight	Mate Value, Air, μg/m3
4-Methyl-benzo[a]anthracene	242	N
1-Methyl-chrysene	242	1.79×10^3
6-Methyl-chrysene	242	1.79×10^3
7,12-Dimethyl-benzo[a]anthracene	256	2.6×10^{-1}
9,10-Dimethyl-benzo[a]anthracene	256	2.96×10^1
Benzo[f]fluoranthene	252	N
Benzo[k]fluoranthene	252	1.63×10^3
Benzo[b]fluoranthene	252	9.0×10^2
Benzo[a]pyrene	252	2.0×10^{-2}
Benzo[e]pyrene	252	3.04×10^3
Perylene	252	N
1,2,3,4-Dibenzanthracene	278	1.0×10^4
2,3,6,7-Dibenzanthracene	278	N
Benzo[b]chrysene	278	N
Picene	278	2.5×10^3
Benzo[c]tetraphene	256	N
Benzo[ghi]perylene	302	5.43×10^2
Coronene	300	N
1,2,3,4-Dibenzpyrene	302	N
1,2,4,5-Dibenzpyrene	302	N
Alkyl substituted naphthalenes	N/A	2.0×10^5
Dibenzothiophene	182	2.3×10^4
Methyl Dibenzothiophene	196	N
Dimethyl phenanthrenes	206	N
Trimethyl phenanthrenes	220	N
Alkyl substituted biphenyl	N/A	N
Ethyl fluorene	195	N

N - Not Available

4.2.4 Level II Analyses

Level II tests were conducted at three of the diesel engine sites previously tested (sites 309, 312 and 313). These were identified as sites 309-2, 312-2 and 313-2. The principal sampling system was the SASS train. The controlled condensation system (CCS) was used to sample for SO_3 emissions. The following SASS train organic samples were composited for analysis: probe rinse, module rinse, filter extract, XAD-2 resin extract. The condensate extract was not composited. Standard Level I analyses were repeated: TCO, GRAV, IR, and LC (followed by GRAV and IR). Level II analysis for the organic and CCS train samples are described below.

Level II Organic Analysis--

Initially all samples listed in Table 27 were screened using a packed Dexil 300 column, (column conditions for Dexil 300 are given in Table 28). With the exception of the blanks, the packed column results suggested that alternative chromatography procedures were required due to highly complex and concentrated mixtures of organics in the samples.

Capillary column chromatography was chosen because previous work on similar samples has shown that the Level I LC separation procedure causes sample modification and losses which are in excess of Level II standards. The LC procedure, however, is adequate for Level I studies, but Level II requires significantly better quantitation. The column chosen was a glass OV-101 wall coated open tube, 30 meters in length. The actual operating conditions for the column are given in Table 28. All samples were analyzed using this capillary column without additional preparation other than the addition of an internal standard.

Prior to capillary column analysis, each sample was spiked with the internal standard, chloronaphthalene, at a level approximating 20 $\mu g/m^3$ emission from the source. Chloronaphthalene was chosen because it elutes at approximately a mid-range in the chromatogram, is very stable, is not a typical combustion product, and yields a unique mass spectrum due to its chlorine isotope pattern.

TABLE 27. LEVEL II SAMPLES ANALYZED FOR INTERNAL COMBUSTION SITES

Sample Code	Description
309-2-XRPF-MRPR	Combination of resin, particle filter, module rinse, and probe rinse extracts
309-2-CD-LE	Condensate extract
309-2-MCB	Methylene chloride blank for condensate extract
309-2-XRBPFB-MAB	Combined blank extractions for resin, particle filter, methylene chloride, and acetone
312-2-XRPF-MRPR	Combination of resin, particle filter, module rinse, and probe rinse extracts
312-2-CD-LE	Condensate extract
312-2-MCB	Methylene chloride blank for condensate extract (used for both 312 and 313 sites)
312-XRBPFB-MAB	Combined blank extractions for resin, particle filter, methylene chloride, and acetone (used for both 312 and 313 sites)
313-2-XRPF-MRFR	Combination of resin, particle filter, module rinse, and probe rinse extracts
313-2-CD-LE	Condensate extract

TABLE 28. LEVEL II ORGANIC ANALYSIS CONDITIONS

Chromatograph Conditions for OV-101 Capillary Column	
Column:	Glass OV-101 wall coated capillary, 30M long by 0.01" id.
Injector:	Operated in a split mode (50:1 split ratio) at 290°C
Temperature Program:	50-270°C at 2°C/min after a three minute delay
Flow Rate:	20 cm/sec (∿1cc/min) of Helium
Injection Size:	5 µl
Total Analysis Time:	∿90 min
Chromatograph Conditions for Dexil 300 Packed Column (sample screening)	
Column:	Glass packed with 3% Dexil 300® on Chromosorb W, 5' long by 2.1 mm id.
Injector:	300°C
Temperature Program:	50-3--°C at 4°C/min
Flow Rate:	30 cc/min of Helium
Injection Size:	1 µl
Total Analysis Time:	∿80 min
Chromatograph Conditions for OV-17 Packed Solumn (LC Fraction Analysis)	
Column:	Glass packed with 3% OV-17 on Chromosorb W, 5' long by 2.1 mm id.
Injector:	270°C
Temperature Program:	50-270°C at 4°C/min
Flow Rate:	30 cc/min of Helium
Injection Size:	1 µl
Total Analysis Time:	∿60 min

The original samples were delivered with corresponding LC fractions. Several of these LC fractions were analyzed both by electron impact (EI) and chemical ionization (CI) GC/MS using an OV-17 packed column (see Table 28 for conditions). The results of all analyses are discussed in detail below.

In an attempt to determine the presence of heteroatom containing organics, several LC fractions were analyzed by GC/MS using both EI and CI modes of ionization. Late eluting fractions (i.e. LC 4-7) which exhibited high TCO and gravimetric numbers were chosen for analysis. Not all of the fractions were available, but enough information was gained to support the conclusion that it is not possible to do Level II analysis of samples fractionated in this way. The purpose of analyzing the LC fractions was to identify compounds at low levels in specific compound classes. Once an identification was made using an LC fraction, that specific compound was searched for in the data obtained on the original sample. This procedure was used to facilitate identification of species at low levels in the rather concentrated samples. When no evidence of the compound was found in the original sample, it was assumed to be a contaminant introduced as a part of the LC procedure. When a compound was confirmed, it was quantitated and reported. As an example of the problems encountered, LC fraction 6 of sample 309-2-XRPF-MRPR contained a rather high concentration of fatty acid methyl esters. The fatty acid methyl esters consisted of a homologues series starting with pentanoic acid methyl ester and extending to pentacosanoic acid methyl ester with every carbon number in between present. Given this information, the data collected from the original sample, using the capillary column, was examined. No evidence of fatty acid methyl esters could be found in the original sample; therefore, these compounds were assumed to be contaminants introduced into the sample by handling (fatty acid methyl esters are found in various hand cream formulations).

This Level II analysis procedure provides information only on the volatile portion of the samples, up to about C_{30}. Materials with high boiling points would not be directly determined. Level II procedures for nonvolatile organics are not well defined at the present time.

Level II Analysis for Sulfur Species--

The Goksoyr-Ross controlled condensation system was used for Level II sampling for sulfur species. Identification and quantitation of these species was accomplished by the following analysis. Aerosol H_2SO_4, a form typically found in combustion gases, was collected in the controlled condensation coil. The coil was completely rinsed with deionized water. The H_2SO_4 concentration in the collected rinse was determined by a bromophenol blue indicated acid-base titration. Sulfur dioxide was collected in the H_2O_2 impinger. A reaction between SO_2 and H_2O_2 formed H_2SO_4 which was quantitatively determined by the Level I turbidimetric sulfate analysis. Sulfates were collected by the filter and/or adhered to the inside of the probe. Sulfates present in the filter washings and probe rinses were also quantitatively determined by the Level I turbidimetric sulfate analysis.

4.2.5 Test Results

Field Measurements and Emissions of Criteria Pollutants--

The operating load, fuel type, and fuel feed rates for the internal combustion sites tested are presented in Table 29. Eleven of the fourteen sites were tested under base load conditions, and the remaining three at slightly derated conditions.

Oxygen concentration data and data on particulate and SO_x emissions and Bachrach smoke readings for the tests conducted are presented in Table 30. Gaseous hydrocarbon (C_1-C_6) measurements were also made in the field but will be reported later along with emissions data for volatile (C_7-C_{16}) and non-volatile ($>C_{16}$) organics. As discussed previously in Section 4.1, the existing data base for NO_x and CO emissions from internal combustion sources is adequate. Additional NO_x and CO measurements were therefore unnecessary. The SO_x emissions data presented were computed from the fuel sulfur content and not based on field measurements.

Particulate emissions determined by weighing filters generally correlate well with Bachrach smoke readings, i.e., higher particulate emissions normally correspond to higher smoke numbers. Also, it may be noted that particulate emissions from distillate oil engines are much higher than particulate emissions from distillate oil-fueled gas turbines. The calculated SO_x emissions are

TABLE 29. OPERATING LOAD AND FUEL FEED RATES OF INTERNAL COMBUSTION SOURCES TESTED

Combustion Source Type	Site No.	Operating Load	% Base Load	Fuel Used	Fuel Rate	Energy Input
Gas Turbine	#110	19.5 MW	94.7%	Natural Gas	7,100 Nm^3/hr	294 GJ/hr
Distillate Oil Turbine	#111	18.0 MW	87.4%	JP-5	7.50 m^3/hr	278 GJ/hr
	#112	22.5 MW	80.4%	JP-5	8.18 m^3/hr	303 GJ/hr
	#306	14.5 MW	100 %	JP-5	5.49 m^3/hr	204 GJ/hr
	#307	14.5 MW	100 %	JP-5	5.49 m^3/hr	204 GJ/hr
	#308	20.2 MW	100 %	JP-5	7.77 m^3/hr	288 GJ/hr
Distillate Oil Reciprocating Engine	#309	2.5 MW	100 %	No. 2 Diesel	0.70 m^3/hr	26.2 GJ/hr
	#310	2.5 MW	100 %	No. 2 Diesel	0.70 m^3/hr	26.2 GJ/hr
	#311	2.5 MW	100 %	No. 2 Diesel	0.70 m^3/hr	26.2 GJ/hr
	#312	2.5 MW	100 %	No. 2 Diesel	1.02 m^3/hr	39.9 GJ/hr
	#313	2.5 MW	100 %	No. 2 Diesel	1.02 m^3/hr	39.9 GJ/hr
	#309-2	2.5 MW	100 %	No. 2 Diesel	0.70 m^3/hr	26.2 GJ/hr
	#312-2	2.5 MW	100 %	No. 2 Diesel	1.02 m^3/hr	39.9 GH/hr
	#313-2	2.5 MW	100 %	No. 2 Diesel	1.02 m^3/hr	39.9 GJ/hr

TABLE 30. PARTICULATE AND SO_x EMISSIONS FROM INTERNAL COMBUSTION SOURCES TESTED

Combustion Source Type	Site No.	O_2 %	Particulate Emissions		SO_x Emissions		Bachrach Smoke No.
			mg/m^3	mg/J	ppm	mg/J	
Gas Turbine	#110	18.50	ND	ND	ND	ND	0
Distillate Oil Turbine	#111	19.40	6.71	21.4	3.4	28.5	3.5
	#112	17.50	2.91	4.2	7.9	30.6	3.0
	#306	14.97	2.46	2.1	<1.9	< 4.2	3.0
	#307	13.45	3.85	2.6	<2.3	< 4.2	4.0
	#308	16.48	4.37	4.9	<1.4	< 4.2	5.0
Distillate Oil Reciprocating Engine	#309	11.11	21.02	11.0	60	83.1	6.5
	#310	13.70	29.41	20.8	81	153	7.0
	#311	15.82	33.15	33.0	58	153	6.5
	#312	11.30	12.44	6.6	43	61.2	ND
	#313	12.88	15.71	10.0	44	74.3	6.0
	#309-2	14.0	14.72	10.8	43	83.3	6.0
	#312-2	12.3	14.87	8.8	67	106	5.0
	#313-2	12.4	19.17	11.5	61	97.0	5.0

ND - Not Determined.

lower than those seen in the stacks of utility boilers, due to both the low sulfur content of the types of fuel used and the large amount of excess air normally present in the combustion gases or turbines and reciprocating engines.

The data reduction procedure for converting emission concentrations (ppmv or mg/m^3) to emission factors (mg/J) is based on calculations of the combustion of fuel with air, as described in detail in Appendix C.

Inorganic Analysis Results--

The inorganic analysis data, generated using the analytical procedures described in Section 4.2.3, are contained in Appendix D in 15 tables. Tables D-1 and D-2 contain the results from the gas turbine site (Site 110). Tables D-3 to D-9 present results from the distillate oil turbine sites (Sites 111, 112, 306, 307 and 308). Tables D-10 to D-15 present results from the distillate oil reciprocating engine sites (Sites 309, 310, 311, 312, and 313). These tabulated results are presented for each section of the SASS train and also are summed to provide a total value. Analytical data for the starting fuels are also shown in these tables (except for Site 110). Mass emissions, in mg/m^3, for each element reported, were calculated based on both the starting fuel analysis (assuming that all of the element exited with the flue gas) and the total catch determined in the SASS samples. Calculated mass emissions were computed using the formula presented in the discussion of analytical detection limits (Section 4.2.3).

A summary of the data from the specific inorganic analyses is given in Table 31. Mercury, arsenic, and antimony emissions were all quite low. From all three source types, these elements were found to be collected primarily in the XAD-2 resin. Chloride and fluoride were found almost exclusively in the XAD-2 resin and composite (acid XAD-2 module rinse plus XAD-2 module condensate plus peroxide impinger) samples.

The SSMS analysis found the major elements present in all sites to be Al, B, Ba, Ca, Cu, Fe, K, Mg, Na, Ni, P, Pb, S, Si, and Zn. In addition, Mn levels were found to be at least a factor of twenty higher for those sites (111, 306, and 307) using an organic manganese fuel additive. The above elements were

TABLE 31. SUMMARY OF RESULTS FROM SPECIFIC INORGANIC ANALYSES

Combustion Source Type	Site No.	Mass Emissions (mg/m^3)						
		Hg	As	Sb	SO_4*	Cl	F	NO_3*
Gas Turbine	110	0.0091	<0.0014	<0.0016	-	0.89	-	-
Distillate Oil Turbine	111	0.00018	<0.0056	<0.0046	-	4.9	0.010	0.029
	112	0.0014	<0.0033	0.013	0.23	2.5	0.049	0.018
	306	<0.00074	<0.00009	0.0017	0.035	-	-	-
	307	0.0016	<0.00011	0.0019	0.018	-	-	-
	308	<0.00033	<0.00019	<0.00016	0.068	-	-	-
Distillate Oil Reciprocating Engine	309	0.00016	<0.00012	<0.00020	0.74	-	-	-
	310	0.00077	<0.00017	<0.0019	0.74	-	-	-
	311	<0.00091	<0.00020	<0.00024	0.98	-	-	-
	312	0.00003	<0.00011	<0.00030	0.50	-	-	-
	313	<0.0011	<0.00011	<0.00019	0.74	-	-	-

*Values are from particulate samples only.

found in the SASS train at levels greater than 1 mg ($\sim$0.003 mg/DSCM) in almost all cases. The complete SSMS data are included in Appendix D.

Results of Level II analyses of the controlled condensation train samples for sulfur species are presented in Table 32.

Organic Analysis Data--

Total Organic Matter -- As has been discussed in preceding paragraphs, the determination of hydrocarbons boiling in the same range as methane through n-hexane is done in the field while the analysis of hydrocarbons boiling in the range of n-heptane (C_7) through n-hexadecane (C_{17}) is performed in the laboratory. The sensitivity of the gas chromatograph in the laboratory is about a thousand times greater than the sensitivity of the instrument taken into the field. The corresponding limit of detection for the field gas

TABLE 32. LEVEL II CONTROLLED CONDENSATION TRAIN ANALYTICAL RESULTS

Sample Number	Sample Type	H_2SO_4 mg/m^3	SO_2 mg/m^3	SO_4 mg/m^3
309-2-GC	Coil rinse	ND	*	*
309-2-GI	H_2O_2 impinger	*	38.96	*
309-2-GP/GF	Probe rinse and filter wash	*	*	1.56
312-2-GC	Coil rinse	1.38	*	*
312-2-GI	H_2O_2 impinger	*	88.64	*
312-2-GP/GF	Probe rinse and filter wash	*	*	1.58
313-2-GC	Coil rinse	1.36	*	*
313-2-GI	H_2O_2 impinger	*	81.20	*
313-2-GP/GF	Probe rinse and filter wash	*	*	1.74

ND indicates not detected

*The sulfur species indicated is not expected to be trapped in this part of the sampling train. Samples collected are therefore not analyzed for the specific sulfur species.

chromotograph is about 1000 μg hydrocarbon/m^3, whereas the laboratory gas chromatograph can detect 1 μg/m^3. This is the principal reason for the apparent absence of the lighter materials, e.g., C_4, C_5 and C_6.

The nonvolatile organic content of the samples is also determined in the laboratory. The procedure has been described briefly earlier in the text.

A summary of all results is presented in Table 33. There is a large variation in the C_1-C_6 concentrations found in testing oil fired turbines (sites 111, 112, 306, 307 and 308). The diesel fuel fired engines (sites 309 through 313) varied in total C_1-C_6 content from 10 mg/m^3 to 30 mg/m^3. Fluctuations in the ethane content of these samples were the most notable.

TABLE 33. VOLATILE AND NONVOLATILE ORGANIC EMISSIONS FROM INTERNAL COMBUSTION SYSTEMS

	Combination Source Type													
	Gas Turbine	Distillate Oil Turbine					Distillate Oil Reciprocating Engines							
Site	110	111	112	306	307	308	309	309-2	310	311	312	312-2	313	313-2
Volatile Organic Gases Analyzed in Field, μg/m^3														
C_1	BL*	BL	BL	BL	BL	BL	1000	500	1570	2570	3285	800	4000	1100
C_2	BL	BL	BL	67620	15130	2275	7765	700	10380	5970	17540	1900	26015	1700
C_3	BL	BL	BL	BL	BL	BL	3535	700	3065	1140	705	BL	745	BL
C_4	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL
C_5	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL
C_6	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL	BL
Volatile Organic Materials Analyzed in Laboratory by GC-TCO Procedure: μg/m^3														
C_7 (B.P. 90-110°C)	483	32	29	100	82	BL	24	10	214	98	585	90	87	BL
C_8 (B.P. 110-140°C)	1202	100	147	52	27	BL	251	370	328	497	251	400	154	560
C_9 (B.P. 140-160°C)	444	137	200	7	5	BL	685	850	633	683	565	1100	301	1290
C_{10} (B.P. 160-180°C)	727	927	613	17	14	99	1488	2410	1516	1228	1704	1800	1034	2120
C_{11} (B.P. 180-200°C)	23	BL	21	89	12	BL	1945	2890	2292	1265	2159	2120	682	2580
C_{12} (B.P. 200-220°C)	BL	84	152	6	15	25	2916	3230	2512	1438	2663	2450	1267	3120
C_{13} (C.P. 220-240°C)	29	BL	56	28	BL	12	4919	3000	3827	2899	3970	2330	1742	2810
C_{14} (B.P. 240-260°C)	BL	BL	BL	210	BL	11	3632	3580	3810	1933	2413	2200	1509	3100
C_{15} (B.P. 260-280°C)	BL	BL	46	484	1	38	3103	2760	4192	1810	2389	2250	1771	3010
C_{16} (B.P. 280-300°C)	BL	BL	457	783	8	71	2606	2290	3746	1941	2149	1680	937	2350
Nonvolatile Organic Matter >C16 From Laboratory Gravimetric Analysis, μg/m^3:	310	6800	3710	440	1400	1270	56180	55380	53880	43040	63590	55040	46680	66340
Total Organics, mg/m^3	3.22	8.08	5.43	69.8	16.7	3.80	89.0	76.8	92.0	66.5	104	71.5	86.9	87.3

*BL Concentration of the species is below the limit of detection of the instrument; 1 ppm (≈1000 μg/m^3) per C_1-C_6 and 0.001 ppm (≈0.5 μg/m^3) per C_7-C_{16}.

The concentration of materials boiling between 90°C and 300°C varied from 200 to 3000 μg/m^3 in the samples from the gas- and oil-fired turbines. The C_6-C_{16} hydrocarbon content of samples from the diesel fuel-fired engines ranged from about 10 to 20 mg/m^3. On the vaerage, the diesel burning engines emitted approximately 15 times more C_6-C_{16} materials than the gas- or oil-fired turbines.

In all cases, the majority of volatile materials were collected in the XAD-2 module, which is designed as the principal organic material collector. This is readily seen from the tabulation of individual sample analyses presented in Table 34. (An explanation of the sample identification codes is given in Figure 9.) Also because of the design, the second highest organic concentration should be and is in the module rinse. Analyses of the Level II samples (309-2, 312-2, 313-2) for volatile organics were performed on composites (i.e., PR+PF+MR+XR and CD) rather than on the individual samples. Therefore, these results are not presented in Table 31.

In a similar manner, the nonvolatile content of the samples from the diesel engine sites 309 through 313 was about 25 times more than the nonvolatile content in the samples taken from the gas- or oil-fired turbine units. The samples from the diesel engine unit contained between roughly 45 and 65 mg/m^3 nonvolatile material, whereas the samples of gas- or oil-fired turbines contained between 300 and 7000 μg/m^3.

Overall, the average total organic content of samples from the gas- or oil-fired turbines was 6 mg/m^3 and the average total organic content of samples from diesel fuel fired engines was 88 mg/m^3.

As with the volatile organics, and for the same reason, the bulk of the nonvolatile materials is in the XAD-2 module. The module rinses from the diesel engine sties 312 and 313 also have a heavy quantity of nonvolatiles. Gravimetric results for individual samples are presented in Table 35.

Organic Component Analysis -- The analysis of the material collected was based on the data in the preceding paragraphs which showed that the only organics of any potential interest were obtained from the XAD-2 module rinse and XAD-2 resin and met the organic analysis criteria explained in Section 4.2.

TABLE 34. RESULTS OF GC-TCO ANALYSIS FOR C_7-C_{16} HYDROCARBONS IN LEVEL 1 SAMPLES

Sample Identification Number	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	Total C_7-C_{16}
				($\mu g/m^3$ of Sample Gas)[*]							
110-PR-O-KD-1	106	153	67	25	23	<1	BL[+]	BL	BL	BL	374
110-XR-Wet-S-GC	†	†	377	357	BL	BL	BL	BL	BL	BL	734
110-XR-Dry-S-GC	BL	1049	BL	345	BL	BL	29	BL	BL	BL	1394
110-XM-S-KD-1	377[‡]	BL	BL	BL	BL	BL	BL	BL	BL	BL	377
111-PR-O-KD[**] Reserve											BL
111-XR-SKD Reserve	32	61	57	912	BL	84	BL	BL	BL	BL	1146
111-XM-S-KD Reserve	BL	37	80	15	BL	BL	BL	BL	BL	BL	132
111-PF-S-KD[**] Reserve											2
112-OR-O-KD-1	29	118	83	21	21	9	BL	BL	BL	BL	281
112-XR-Wet-S-GC	BL	†	56	394	BL	113	56	BL	BL	244	863
112-XR-DRY-S-GC	†	†	61	198	BL	30	BL	BL	46	213	548
112-XM-S-KD-1[**]											29

(Continued)

[*] Corrected for blanks

[+] BL indicates below detection limit (0.5 $\mu g/m^3$)

[†] Peaks, if any, obscured on shoulder of solvent peak

[‡] Response possibly caused by traces of methanol not removed during K-D concentration

[**] Total less than 75 $\mu g/m^3$, so quantities in each range are not reported.

TABLE 34. (CONTINUED)

Sample Identification Number	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	Total C_7-C_{16}
				(μg/m^3 of Sample Gas)[*]							
306-PR	BL	BL	BL	BL	BL	BL	23	BL	149	188	360
306-XR	100	52	7	17	89	6	5	210	335	595	1416
306-PF[+]											34
307-PR[+]											BL
307-XR	82	27	5	14	12	15	BL[†]	<1	1	8	164
307-PF[+]											35
308-PR[+]											BL
308-MR[+]											
308-XR	BL	<1	BL	99	BL	25	12	11	38	71	257
308-CDS[+]											19
308-PF[+]											BL
309-PR[+]											30
309-MR	24	<1	<1	<1	<1	2	6	14	38	150	234
309-XR	0	251	685	1488	1945	2914	4913	3618	3065	2456	21335
309-CDS[+]											8
309-PF[+]											5
309-2[+]											21

(Continued)

[*] Connected for blanks

[+] Total less than 75 μg/m^3, so quantities in each range are not reported.

[†] BL indicates below detection limit (0.5 μg/m^3)

TABLE 34. (CONTINUED)

Sample Identification Number	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	Total C_7-C_{16}
				(μg/m³ of Sample Gas)[*]							
310-PR[+]											30
310-MR	7	<1	<1	<1	<1	21	129	164	462	611	1394
310-XR	207	323	611	1486	2200	2426	3639	3554	3508	3006	20960
310-CDS[+]											3
310-PF	BL[†]	5	22	29	92	65	59	92	222	129	715
311-PR[+]											7
311-MR	BL[†]	<1	<1	<1	<1	<1	45	38	396	523	992
311-XR	98	497	683	1228	1265	1438	2854	1895	1424	1418	12800
311-CDS[+]											42
311-PF[+]											40
312-PR[+]											5
312-MR	386	BL	3	1	3	9	44	139	393	417	1495
312-XR	110	239	534	1652	2100	2614	3895	2250	1956	1621	16971
312-CDS	35	12	24	31	19	11	5	6	18	2	164
312-PF	54	1	4	19	37	30	25	18	22	9	218
312-2											16

(Continued)

[*] Corrected for blanks.

[+] Total less than 75 μg/m³, so quantities in each range are not reported.

[†] BL indicates below detection limit (≈0.5 μg/m³)

TABLE 34. (CONTINUED)

Sample Identification Number	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	Total C_7-C_{16}
				($\mu g/m^3$ of Sample Gas)[*]							
313-PR[+]											36
313-MR	BL[†]	BL	BL	BL	6	5	18	75	248	287	640
313-XR	10	154	300	1032	672	1261	1706	1433	1457	646	8671
313-CDS	59	BL	1	2	3	1	1	1	14	2	84
313-PF	18	<1	<1	<1	<1	<1	18	<1	52	3	91
313-2[+]											21

[*] Corrected for blanks.

[+] Total less than 75 $\mu g/m^3$, so quantities in each range are not reported.

[†] BL indicates below detection limit ($\approx 0.5\ \mu g/m^3$).

XXX-XX-XX-XXX-XX-X

SITE IDENTIFICATION	SAMPLE TYPE	SAMPLE PREPARATION	FIRST LEVEL ANALYSIS		SECOND LEVEL ANALYSIS	THIRD LEVEL ANALYSIS
Consecutively numbered by sampling team:	Numbers and corresponding sample types are as follows:	Numbers and corresponding preparation steps are as follows:	Numbers and corresponding procedures are as follows:		Organic analyses on conc samples will be coded as follows:	Resulting LC fractions for grav./IR/LRMS analyses will be numbered in order, 1-8
			Organic	Inorganic		
100-199, TRW West Coast 200-299, TRW East Coast 300-399, GCA	1-bulk liquid (separated from a slurry) 2-bulk liquid (separated from a slurry) 3-bulk liquid 4-bulk liquid FF-liquid fuel feed CD-condensate from XAD-2 module PR-solvent probe/ cyclone rinse MR-solvent XAD-2 module rinse HM-HNO_3 XAD-2 module rinse HI-H202 impinger AI-APS impingers XR-XAD-2 resin PF-filter(s) 1C-1-3μ cyclone 3C-3-10μ cyclone 10C->10μ cyclone XM-XR extract plus MR CH-HM plus CD plus HI FC-PF plus 1C CC-3C plus 10C CF-solid fuel feed (coal) 5-bulk solids 6-bulk solids 7-bulk solids (separated from a slurry) 8-bulk solids (separated from a slurry)	0-no preparation LE-liquid-liquid extraction SE-Soxhlet extraction A-acidified aliquot B-basified aliquot PB-Parr bomb combustion HW-hot water extraction AR-aqua regia extraction	0-no conc required GC-C_7-C_{17} GC KD-K-D Conc	SS-SSMS AAS-Hg,As,Sb SO_4-SO_4 NO_3-NO_3 CF-Cl,F	GM-GC/MS for PAHs GI-Grav.,IR MS-LRMS LC-LC separation	

Figure 9. EACCS Sample Control Numbers

TABLE 35. GRAVIMETRIC RESULTS FOR INTERNAL COMBUSTION SITES

Sample Identification Number	Residue Weight (mg)	Aliquot Factor	Total Weight (mg)	Blank Corrected Weight (mg)	Net Sample Nonvolatile Content (mg/m^3)
110-XR-Wet-S-KD-2	11.7	x 10	117.2	0	0
110-XR-Dry-S-KD-2	9.9	x 10	98.8		
110-PR-O-KD-2	0.4	x 10	3.7	3.4	0.1
110-XM-S-KD-2	0.6	x 10	6.5	6.0	0.2
111-XR-S-KD-2	38.7	x 10	386.7	147.9	4.9
111-PR-O-KD-2	4.3	x 10	43.3	42.8	1.4
111-XM-S-KD-2	0.6	x 10	6.4	6.0	0.2
111-PF-S-KD-2	1.0	x 10	9.8	8.6	0.3
112-XR-Wet-S-KD-2	19.4	x 10	194.0	107.8	3.3
112-XR-Dry-S-KD-2	15.3	x 10	152.6		
112-PR-O-KD-2	0.4	x 10	3.7	3.4	0.1
112-XM-S-KD-2	1.0	x 10	10.0	9.7	0.3
306-PR	0.5	0.2 x 0.75	3.33	1.11	0.03
306-MR	0.6	0.2 x 0.75	4.00	1.78	0.05
306-XR	3.8	0.2 x 0.95	20.00	12.8	0.35
306-PF	0.1	0.2 x 0.49 x 0.75	1.36	0.30	0.01
306-CDS[a]					

[a] Not analyzed because of small condensate volume.

(Continued)

TABLE 35. (CONTINUED)

Sample Identification Number	Residue Weight (mg)	Aliquot Factor	Total Weight (mg)	Blank Corrected Weight (mg)	Net Sample Nonvolatile Content (mg/m^3)
307-PR	0.5	0.2 x 0.75	3.33	0	0
307-MR	0.7	0.2 x 0.75	4.67	0	0
307-XR	8.2	0.2 x 0.95	43.16	43.16	1.40
307-PF	0.1	0.2 x 0.50	1.00	0	0
307-CDS	0.5	0.2 x 0.75 x 0.67	4.98	0	0
308-PR	0.7	0.2 x 0.75	4.66	4.66	0.15
308-MR	1.0	0.2 x 0.75	6.67	6.67	0.22
308-XR	5.5	0.2 x 0.95	28.95	21.99	0.71
308-PF	0.1	0.2 x 0.51	0.01	0.01	0
308-CDS	0.5	0.2 x 0.75 x $\frac{100}{178}$	5.93	5.93	0.19
309-PR	0.7	0.2 x 0.75	4.67	4.67	0.16
309-MR	74.6	0.2 x 0.75	497.33	497.33	17.47
309-XR	208.2	0.2 x 0.95	1,095.79	1,080.19	37.95
309-PF	0.0	0.2 x 0.47 x 0.75	0.00	0.00	0.00
309-CDS	1.5	0.2 x 0.75 x $\frac{150}{248}$	17.20	17.20	0.60
310-PR	0.7	0.2 x 0.75	8.67	1.89	0.07
310-MR	77.3	0.2 x 0.75	515.33	505.61	17.88
310-XR	199.2	0.2 x 0.95	1,048.42	1,004.72	35.52
310-PF	1.1	0.2 x 0.53	10.38	6.78	0.25
310-CDS	1.0	0.2 x 0.75 x $\frac{250}{258}$	12.93	4.53	0.16

(Continued)

TABLE 35. (CONTINUED)

Sample Identification Number	Residue Weight (mg)	Aliquot Factor	Total Weight (mg)	Blank Corrected Weight (mg)	Net Sample Nonvolatile Content (mg/m^3)
311-PR	2.9	0.2 x 1.00	14.50	11.32	0.39
311-MR	72.2	0.2 x 0.75	481.33	477.77	16.56
311-XR	125.8	0.2 x 0.95	662.11	634.84	21.98
311-PF	10.2	0.2 x 0.50	102.00	100.2	3.47
311-CDS	2.1	0.2 x 1.0 x 0.5085	20.65	18.65	0.64
312-PR	1.0	0.2 x 0.75	6.67	3.73	0.12
312-MR	131.6	0.2 x 0.75	877.33	873.12	29.17
312-XR	196.5	0.2 x 0.95	1,034.21	1,007.57	33.66
312-PF	0.6	0.2 x 1.0 x 0.5028	5.97	4.17	0.14
312-CDS	2.3	$0.2 \times 0.75 \times \frac{400}{542}$	20.78	15.04	0.50
313-PR	2.0	0.2 x 0.75	13.33	1.69	0.06
313-MR	49.7	0.2 x 0.25	994.00	991.00	32.94
313-XR	78.6	0.2 x 0.95	413.68	392.89	13.06
313-PF	0.6	0.2 x 1.0 x 0.4471	6.71	1.25	0.04
313-CDS	4.1	0.2 x 0.75 x 0.6947	39.35	17.33	0.58

In the case of the gas turbines, only the oil-fueled sources had enough material to warrant liquid chromatography fractionation. Of these samples, sites 111 and 112 XAD-2 resin extracts had a contamination/blank problem and it is not clear whether LC fractional was warranted by Level I criteria. In any event, the level of material was at the borderline of criteria limits and LC fractionation on those samples showed only species associated with the blank could be identified. Sites 306-308 were treated in the normal manner.

Sites 309-313 were electrical generators powered by diesel engines. These sites as shown in Table 33 produced substantial quantities of material, almost all of which was collected in the XAD-2/module rinse sample. This large and extraordinary complex mixture produced the opposite problem in that it taxed the Level I procedures to the point where very little useful information was obtained. This is explained in detail below.

Oil- and Gas-Fueled Turbines (Sites 110-112, 306-308) - Infrared Analysis -- Infrared spectra were obtained on the nonvolatile residues of both the original organic sample concentrates and all liquid chromatography sample fractions. A listing of classes of compounds identified in these spectra is provided in Table 36. Of the compounds listed, benzoates, phthalates, and glycols are contaminants commonly found in blanks, and they should not be considered as emissions. These compounds are ubiquitous, e.g., phthalates are common plasticizers, and avoiding contamination by them is extremely difficult. Silica is from the partial decomposition of the chromatographic column. Because the column packing is silica gel which is slightly soluble in alcohols and acids, silica is generally found in fractions 6-8.

The infrared spectra of samples for Sites 306 through 308 were obtained on a spectrometer which, although in conformance with instrument specifications for Level I analysis, was insufficiently sensitive to produce a readable spectrum of the very small amounts of material available. Table 37 shows that only very intense absorption bands were noticeable, such as those produced by alkyl and aryl groups and C=O and C-O stretching.

Liquid Chromatographic Fractionation - Oil-Fueled Gas Turbine -- In the case of Sites 110 through 112, the level of contamination in the resin was considered too great for a fractionation procedure to provide useful information.

TABLE 36. CLASSES OF COMPOUNDS IDENTIFIED IN INFRARED SPECTRA OF SAMPLE CONCENTRATES AND LC FRACTIONS

Site	Residue of Original Sample	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
110	Esters: includes benzoates, phthalates and vinyl ester; amide; glycol; aldehyde; chlorinated compound; other benzene derivatives.	*	*	*	*	*	Esters: includes vinyl ester; aldehyde/ketone; aromatic nitro compound; other organic nitrate; silica	Esters: includes vinyl ester; aldehyde/ketone; aromatic nitro compound; other organic nitrate; silica	Esters (trace); silica; water
111	Aliphatic hydrocarbons; esters: includes benzoates phthalates and vinyl ester; amide; glycol; aldehyde; chlorinated compound; other benzene derivatives; inorganic sulfate	Aliphatic hydrocarbons	*	*	*	*	Esters: includes vinyl ester; aldehyde/ketone; glycol; aromatic nitro compound; other organic nitrate	Esters: includes vinyl ester; aldehyde/ketone; glycol; aromatic nitro compound; other organic nitrate	Esters (trace); silica; water
112	Esters: includes benzoates and phthalates; glycol, aldehyde; chlorinated compound; other benzene derivatives	*	*	*	*	*	*	*	*

*Insufficient material was found in these samples to justify further analysis.

TABLE 37. CLASSES OF COMPOUNDS IDENTIFIED IN INFRARED SPECTRA OF LC FRACTIONS OF SAMPLES FROM OIL-FUELED GAS TURBINES

Site	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
306	*	*	*	*	*	Species containing alkyl, unsaturated aliphatics, aryl, carbonyl and C-O-X groups[†]	*	*
307	*	*	*	*	*	Species containing alkyl and C-O-X groups - all aliphatic	*	*
308	Aliphatics	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl, carbonyl and C-O-X groups	Species containing alkyl, aryl, carbonyl and C-O-X groups	Species containing alkyl, aryl, carbonyl, aliphatic C-O-X and unsaturated aliphatic groups	Species containing alkyl, aryl, unsaturated aliphatics, carbonyl and C-O-X groups	Species containing alkyl and C-O-X groups - all aliphatic

[*] Insufficient material was found in these samples to justify further analysis

[†] X group in C-O-X linkages was not identified in any sample

Liquid chromatographic separations were performdd on the mixed XAD-2 resin extract and the module rinse samples from the oil-fired units at Sites 306, 307 and 308. The analysis results, in Table 38, showed the predominant amount of material to be in the nonvolatile portion. There is no apparent trend among these samples as to what fraction contains the most material, although fractions 1 and 6 are reasonably heavy in all three cases. Fraction 1 contains almost all aliphatic and some aromatic hydrocarbons; fraction 6 contains such polar species as esters and other carboxylic acid derivatives, aldehydes and ketones, phenolics and amines.

Organic Analysis of Diesel Engine Sites 309-313 -- The data tabulated in Table 33 show that substantial quantities of material were collected in the XAD-2 module rinse samples and, as a result, liquid chromotographic (LC) separation was required for all sites. In addition, the nonvolatile organic material averaged 1.6 g per site which is 30-160 times greater than that which was routinely found in previous sites. As a result, the aliquoting procedure yielded samples that were far too concentrated for the LC columns that were used. This caused the columns to overload and no meaningful separation was effected. A second set of columns was run with less material, but the large amount of hydrocarbon oils present overloaded the early stages (Fractions 1-3) of the columns, and again prevented any meaningful interpretation of the data. This smearing of components throughout the LC fractions is illustrated in Table 39 which tabulates the infrared assignments for these columns and where it is clearly evident that the same components are present in all fractions. More detailed assignments could not be made due to the extraordinary complexity of the mixture and the lack of resolution on the instrument that was used.

Similar results were obtained from the Level II tests at Sites 309, 312, and 313. Table 38 presents a summary of LC, TCO, and GRAV results which may be compared with results from oil-fired turbine Sites 306-308. Large amounts of hydrocarbon oils again caused smearing in the LC separations. IR interpretations of LC fractions from Sites 309-2, 312-2, and 313-2 are presented in Table 39.

TABLE 38. LC/TCO/GRAV SUMMARY FOR SASS SAMPLES FROM SITES 306-313-2

Site-Sample		LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8	Total
306-XR+MR	TCO, mg	*	*	*	*	*	*	*	*	-
	GRAV, mg	0.7	0.3	0.1	0.5	0.4	2.8	BL	*	4.8
	Total, mg/m^3	+	+	+	+	+	+	+	+	+
307-XR+MR	TCO, mg	BL	BL	BL	BL	BL	BL	BL	*	BL
	GRAV, mg	0.5	0.3	0.3	0.3	BL	1.1	0.9	*	3.4
	Total, mg/m^3	0.016	0.0097	0.0097	0.0097	BL	0.036	0.029	*	0.11
308-XR+MR	TCO, mg	BL	BL	BL	BL	BL	BL	BL	*	BL
	GRAV, mg	1.7	0.6	0.4	0.5	0.6	2.6	4.1	1.0	11.5
	Total, mg/m^3	0.055	0.0194	0.0129	0.0162	0.0194	0.0841	0.133	0.034	0.374
309-2-XR+PF+MR+PR	TCO, mg	611	1.62	0.10	10.8	0.07	BL	BL	†	624
	GRAV, mg	892	57.2	77.8	94.7	46.5	16.8	534	†	1719
	Total, mg/m^3	48.1	1.88	2.52	3.38	1.49	5.37	17.0	†	79.7
312-2-XR+PF+MR+PR	TCO, mg	220	2.42	BL	0.57	BL	0.48	BL	†	223
	GRAV, mg	954	34.1	71.3	83.8	48	127	16.7	†	1335
	Total, mg/m^3	38.4	1.19	2.33	2.76	1.57	4.17	0.55	†	51
313-2-XR+PF+MR+PR	TCO, mg	190	4.4	0.53	BL	BL	1.4	BL	†	196
	GRAV, mg	1395	153	48.2	33.6	59.8	102	31.6	†	1823
	Total, mg/m^3	50.9	5.05	1.57	1.08	1.92	3.32	1.02	†	64.9

*Data not required.

+Total not meaningful because of lack of TCO data.

†Fraction 8 is no longer part of the Level I scheme.

TABLE 39. CLASSES OF COMPOUNDS IDENTIFIED IN INFRARED SPECTRA OF LC FRACTIONS OF SAMPLES FROM DISTILLATE OIL RECIPROCATING ENGINES

Site	LC1	LC2	LC3	LC4	LC5	LC6	LC7	LC8
309	Species containing alkyl, aryl and C-O-X groups[a]; carboxylic acid	Species containing alkyl, carbonyl, and C-O-X groups	Species containing alkyl, alkenyl, aryl, carbonyl and C-O-X groups	Species containing alkyl and C-O-X groups - all aliphatic	Species containing alkyl, alkenyl and C-O-X groups - all aliphatic	Species containing alkyl, arly, carbonyl and C-O-X groups	Only aliphatic species	Species containing alkyl and C-O-X groups - all aliphatic
309-2	Species containing hydrocarbons and **ethers**	Species containing hydrocarbons and possibly **ethers**	Species containing hydrocarbons and possibly nitro compounds	Species containing hydrocarbons, ketones, esters,	Species containing saturated and unsaturated ketones	Species containing aldehydes, ketones, esters	Species containing hydrocarbons, esters, ketones	*
310	Only aliphatic species	Only aliphatic species	Only aliphatic species	Species containing alkyl, arly and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups
311	Species containing alkyl and aryl groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, alkenyl, aryl and C-O-X groups	Species containing alkyl, alkenyl, arly and C-O-X groups	Species containing alkyl, alkenyl, aryl, carbonyl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups
312	Species containing alkyl and aryl groups	Species containing alkyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Only aliphatic species	Species containing alkyl, alkenyl, aryl and C-O-X groups	Species containing alkyl, alkenyl, aryl and C-O-X groups	Species containing alkyl, aryl and C-O-X groups	Only aliphatic species
312-2	Species containing hydrocarbons	Species containing hydrocarbons, unsaturated or aryl esters, ketones	Species containing hydrocarbons, unsaturated or aryl esters	Species containing hydrocarbons, saturated ketones	Species containing unsaturated or aryl esters, ketones	Species containing esters, aldehydes, ketones	Species containing unsaturated or aryl esters, ketones	*
313	Species containing alkyl, aryl and C-O-X groups	Only aliphatic species	Species containing alkyl, alkenyl aryl, carbonyl and C-O-X groups	Only saturated and unsaturated aliphatic species	Only aliphatic species	Species containing alkyl, alkenyl, aryl and C-O-X groups	Species containing alkyl and aryl groups	No data
313-2	Species containing hydrocarbons	Species containing hydrocarbons, esters, ketones	Species containing hydrocarbons, esters, ketones	Species containing hydrocarbons	Species containing saturated ketones, aryl or unsaturated esters	Species containing esters, ketones	Species containing esters, ketones, amides, amines unsaturated or aryl ketones	*

[a] X group in C-O-X linkages was not identified in any sample.

In order to further identify potential components of these mixtures, a selected set of liquid chromatographic fractions were analyzed by low resolution mass spectroscopy. These results are shown in Table 40. Again the specific assignments could not be made due to the complexity of the mixtures. However, it is clear that the major portion of the sample consists of hydrocarbon oils and aromatic compounds. Previous experience indicates that the presence of dioctyl phthalate and fatty acid esters are the result of sample contamination. Dioctyl phthalate is a common plasticizer, and fatty acid esters are ingredients in many hand lotions. Thus, contamination by these compounds is difficult to prevent. Because of the complexity of the samples and the contamination problems, assignments should be considered tentative.

Gas Chromotography/Mass Spectroscopy (GC/MS) for Polycyclic Organic Matter (POM) -- All samples obtained at the oil and gas-fueled gas turbine facilities and which were subjected to TCO and gravimetrics analysis were analyzed by GC/MS for POM compounds. Gas chromatography/mass spectroscopy on these samples was not possible by the normal procedure used on this program because the hydrocarbon oils masked the POM spectra to the point of preventing unequivocal identification and quantification. As a result, a POM clean-up procedure, as developed by Battelle-Columbus, was used to remove the oils. This consisted of separating 10 percent of the sample on the standard Level I liquid chromotography column and combining fractions 2, 3, and 4. This resulted in substantial improvement in the samples, but column smearing of the hydrocarbon oils still compromised the results shown in Table 41. However, because all components that were found were several orders of magnitude below the level of concern (see Section 4.3.4), these data are considered adequate.

Level II Organic Analysis by GC/MS -- Table 41 also presents summary results at the Level II GC/MS analyses. Detailed results are given in Appendix Tables D-16 to D-21. The samples consist mainly of saturated and unsaturated hydrocarbons and aromatics. Some POM compounds were detected but only at very low levels. The majority of organic material was found in the sample composite which included the XAD-2 resin extract. Only low levels of organic material were found in the condensate extract; and the blanks were unusually clean. The majority of aromatics found were substituted

TABLE 40. LOW RESOLUTION MASS SPECTROSCOPY RESULTS FOR DIESEL ENGINE SITES

Sample Identification Number	Hydrocarbon Oil	Aromatics	Dioctyl Phthalate	Fatty Acid Esters	Other
309-XM-LC1	+[*]		tr	+	Di-tert-butyl phenol (possible)[†]
310-XM-LC1	+	+	+	+	Anisole (possible)
310-XM-LC6	+	+	+		
310-XM-LC7	tr		tr		
311-XM-LC1	+	+	+		Di-tert-butyl phenol (possible)
311-XM-LC3	+	+	+	+	
311-XM-LC4	+		+		Nonyl phenol (possible)
312-XM-LC1	+		+		Di-tert-butyl phenol (possible)
312-XM-LC3	+	+	+		
312-XM-LC4	+	+	+		Trimethyl naphthalene (possible)
312-XM-LC6	+	+	+		Anisole (possible)
313-XM-LC1	+		+		Di-tert-butyl phenol (possible)

[*] + means the particular species was present.

[†] possible means the compound named is most probably the species present.

TABLE 41. POM EMISSIONS FROM DIESEL ENGINE SITES 309-313* ($\mu g/m^3$)

Compound	309	309-2	310	311	312	312-2	313	313-2
Naphthalene	16	170	18	36	BL	58	3	220
Methylnaphthalenes	BL	461	22	BL	BL	570	BL	590
C_2-substituted naphthalenes	30	506	12	64	BL	798	BL	1090
C_3-substituted naphthalenes	8	631	4	BL	BL	266	BL	672
C_4-substituted naphthalenes	BL	462	BL	BL	BL	BL	BL	28
C_5-substituted naphthalenes	BL	120	BL	BL	BL	BL	BL	BL
Biphenyl	2	T+	6	10	BL	BL	15	37
Methylbiphenyls	BL	BL	BL	BL	BL	BL	BL	150
C_3-substituted biphenyls	BL	BL	BL	BL	BL	BL	BL	BL
Dibenzothiophene	5	BL	2	BL	BL	BL	BL	BL
Methyldibenzothiophenes	BL	BL	0.8	BL	BL	BL	BL	BL
Phenanthrene	8	94	3	BL	BL	38	BL	92
Methylphenanthrenes	20	86	8	60	77	22	150	T
Dimethylphenanthrenes	4	BL	0.8	24	46	BL	58	BL
Trimethylphencenthrenes	BL	BL	2	BL	12	BL	15	BL
Ethylfluorene	BL	24	BL	BL	BL	BL	BL	BL
Pyrene	BL	T	BL	BL	BL	BL	BL	T
Detection limit, $\mu g/m^3$	0.08	0.05	0.08	0.08	0.08	0.05	0.1	0.05

*POMs were found only in XAD-2/XAD-2 module rinse samples

+T indicates trace, 0.5-1.0 $\mu g/m^3$

naphthalenes, and the hydrocarbons were for the most part saturated branched and straight chain molecules.

Some oxygenated organics were found which can be classified as aromatics - aldehydes and esters, including phthalates. The phthalates are ubiquitous; their source is indeterminate, and it is questionable whether they are actually products of combustion. Oxygenates found in the original samples were also found in the LC fractions. However, no other heteroatomic organic compounds were found.

As an example of the complexity of the capillary GC/MS data. Figure 10 shows the reconstructed gas chromatogram for sample 309-2-XRPF-MRPR. Figure 11 is a mass chromatogram of the same sample for M/e = 57 which shows the presence of nonaromatic (i.e., saturated and unsaturated) hydrocarbons. This type of data presentation illustrates at a glance the amount of hydrocarbon compounds present in the sample. Comparing Figures 10 and 11 shows that the bulk of compounds detected (Figure 10) are saturated straight chain and branched hydrocarbons (Figure 11).

The detection limit for these Level II analyses has been established at 0.05 $\mu g/m^3$ based on the analysis of standards. This detection limit is based on instrument performance only and does not consider sample losses during the preparation phase or the efficiency of the sampling device.

It was noted earlier that Level II analysis techniques were not sufficiently well defined for analyzing the nonvolatile residues of the Level II samples. However, an indirect measure of the composition of these higher boiling organic organic compounds can be made by assuming that high molecular weight nonvolatile species would be represented by lower molecular weight homologues. Based on this assumption, the nonvolatile portion of the sample should consist of hydrocarbon tars, primarily straight and branched chain compounds with some aromatic species at low concentrations.

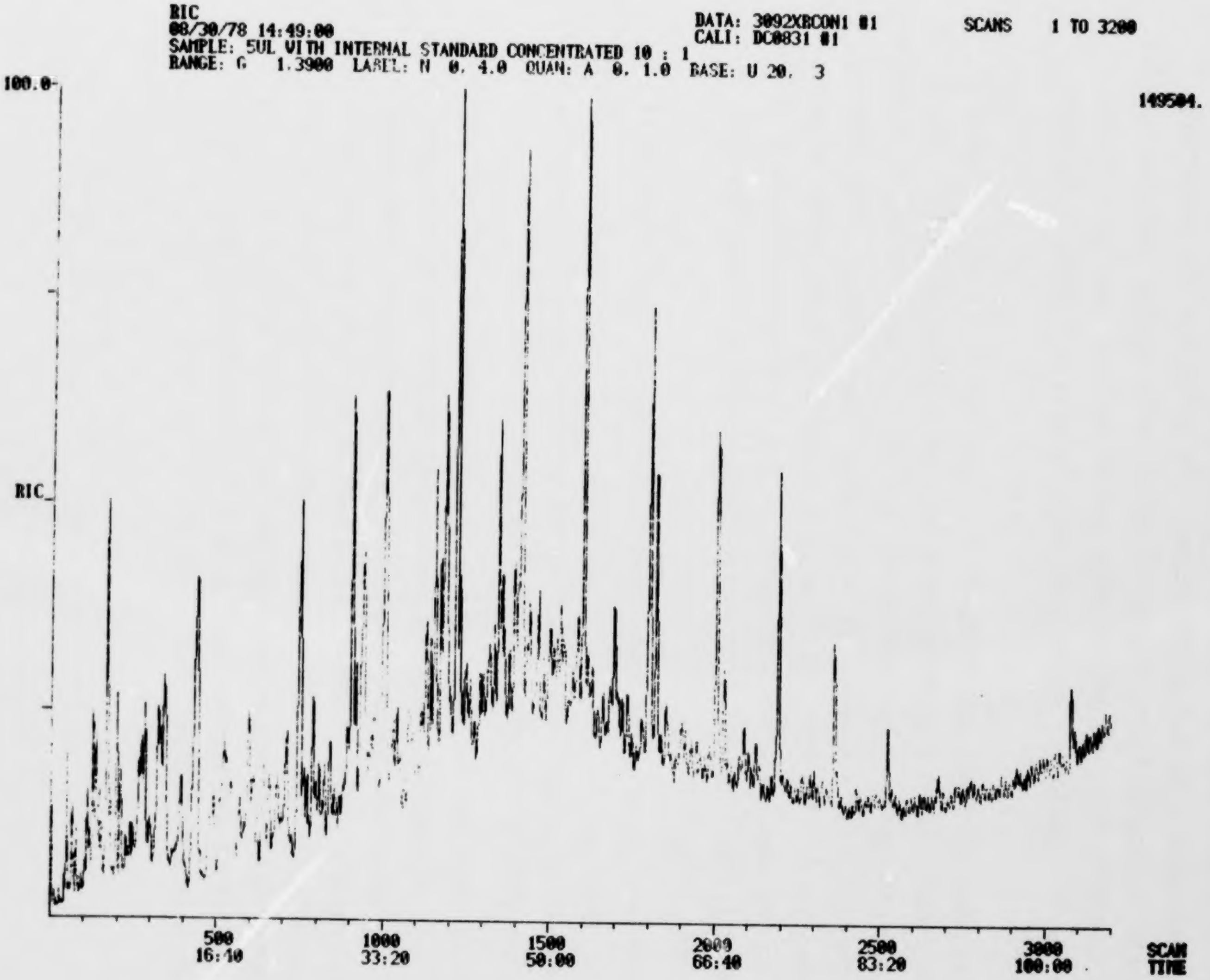


Figure 10. Reconstructed Gas Chromatogram of Sample 309-2-XRPF-MRPR

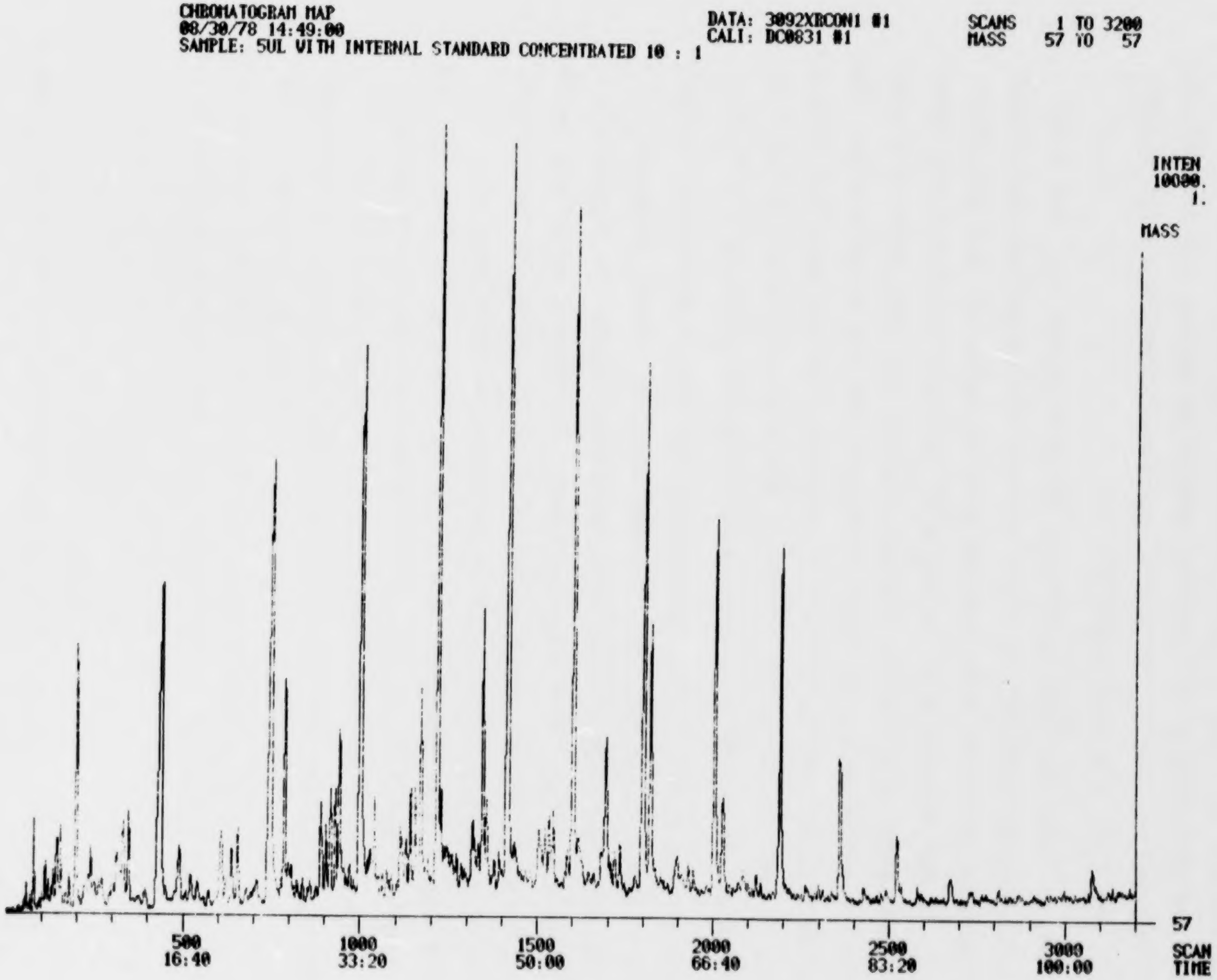


Figure 11. Mass Chromatogram of M/e = 57 Showing Non-Aromatic Nature of Sample 309-2-XRPF-MRPR

4.3 ANALYSIS OF TEST AND DATA EVALUATION RESULTS

4.3.1 Emissions of Criteria Pollutants

The particulate and total organics emissions data collected in this sampling and analysis program for internal combustion sources are presented in Table 42. In addition, the SO_x emissions, calculated from the weight percent of sulfur in the fuel, are also presented.

As shown in Table 42, data variability for particulate, SO_x, and total organics emissions is large for the distillate oil-fueled gas turbines tested. By comparing these emissions data with the existing emissions data presented in Table 12, it may be noted that the SO_x emissions data are within the range of existing emissions data, whereas the particulate data show lower emissions and the total organics data show higher emissions than the existing data. The larger variability for particulate and SO_x emissions are the result of inherent variability in the ash and sulfur content of the JP-5 fuel used, and the five data points acquired provide a valuable addition to the existing data base.

It may also be recalled that for three of the five distillate oil-fueled gas turbines tested (Site Nos. 111, 306, and 307), an organic manganese additive was used to reduce visible smoke emissions. Hence the particulate emissions were lower than those normally found. The organic emissions, on the other hand, were higher than those in the existing data base for two reasons. First, some of the distillate oil-fueled gas turbines tested were not functioning properly, as indicated by the high C_2 emissions for Site Nos. 306 (C_2 = 50.5 ppmv) and 307 (C_2 = 11.3 ppmv). Second, the total hydrocarbon emissions determined by previous investigators were obtained using gas chromatography with flame ionization detector, and some of the heavier hydrocarbons were probably condensed in the sampling line and not measured*. The slight malfunctioning of some distillate oil-fueled gas turbines, however, may represent the real situation for the electricity generation turbine population.

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*The total hydrocarbons normally reported may be equivalent to the C_1-C_6 hydrocarbons measured by TRW/GCA in the field.

TABLE 42. SUMMARY OF EMISSION FACTOR DATA FOR PARTICULATE, SO_x AND TOTAL ORGANICS FROM INTERNAL COMBUSTION SOURCES TESTED

		Emission Factor, ng/J		
Combustion Source Type	Site No.	Particulate	SO_x	Total Organics
Gas-Fueled Gas Turbine	#110	ND	ND	11.1
Distillate Oil-Fueled Gas Turbine	#111	21.4	28.5	27.9
	#112	4.2	30.6	9.0
	#306	2.1	<4.2	57.8
	#307	2.6	<4.2	2.8
	#308	4.9	<4.2	7.5
	Mean $\bar{x}$	7.0	14.3	21.0
	s($\bar{x}$)	3.6	6.2	10.2
	ts($\bar{x}$)/$\bar{x}$	1.4298	1.2038	1.3425
Distillate Oil Reciprocating Engine	#309	11.0	83.1	47.7
	#310	20.8	153.1	65.9
	#311	33.0	153.1	74.1
	#312	6.6	61.2	54.6
	#313	10.0	74.3	54.4
	#309-2	10.8	83.3	58.2
	#312-2	8.8	106.3	45.8
	#313-2	11.5	97.0	54.4
	Mean $\bar{x}$	14.1	101.4	56.9
	s($\bar{x}$)	3.1	12.2	3.3
	ts($\bar{x}$)/$\bar{x}$	0.5176	0.2856	0.1366

ND - Not determined

s($\bar{x}$) = Standard deviation of the mean

ts($\bar{x}$)/$\bar{x}$ = Variability

The higher total organics emissions data should therefore be included in the usable data base. For electricity generation gas-fueled gas turbines, the one data point on total organics emissions is well within the range of existing emissions data for total hydrocarbons presented in Table 11.

For electricity generation distillate oil reciprocating engines, existing data on particulate and SO_x emissions are not available. Variability for the particulate emissions data collected in this program is 0.52 and is considered acceptable. Variability for the SO_x emissions data is 0.26 and is considered acceptable. Variability for the total organics emissions is also less than 0.7. In fact, all the organic emissions data collected are well within the range of existing organic emissions data presented in Table 20.

In Table 43, the emission factors for gas and distillate oil-fueled gas turbines calculated from data collected in this program and the emission factors derived from existing data are compared with the EPA AP-42 emission factors (Reference 23). For industrial gas-fueled gas turbines, the EPA emission factors were all based on the Southwest Research Institute (SWRI) data (References 11 and 16), whereas the emissions data for the McGowin and Durkee reports (References 15 and 3) in addition to the SWRI data have been used in the computation of the existing data emission factors. As noted in Table 43, the EPA and the emission factors calculated from existing data are almost identical for industrial gas-fueled gas turbines.

For industrial distillate oil-fueled gas turbines, the EPA and existing data emission factors for NO_x are again almost identical, but the existing data emission factor for hydrocarbons is 79 percent lower and that for CO is 114 percent higher than the EPA emission factors. The existing data emission factors for CO and hydrocarbons should be considered more reliable than the EPA emission factors, because the existing data base for CO and hydrocarbon emissions is adequate and the basis for the EPA emission factors is not well documented.

For electricity generation gas-fueled gas turbines, the one data point collected on emissions of total organics is in good agreement with the mean emission factor for hydrocarbons based on existing data. Generally, there is also good agreement between the EPA and the existing data emissions factors,

TABLE 43. COMPARISON OF CRITERIA POLLUTANT EMISSIONS FACTORS FOR GAS AND DISTILLATE OIL-FUELED GAS TURBINES

		Emission Factor, ng/J				
Combustion Source Type	Data Source	NO_x	HC	CO	Part	SO_x
Industrial Gas-Fueled Gas Turbines	Existing Data	130	8.6	48.8	ND	ND
	EPA	123	9.4	49.1	ND	0.26
Industrial Distillate Oil-Fueled Gas Turbines	Existing Data	207	3.6	101	ND	ND
	EPA	208	17.0	47.1	15.3	430S
Electricity Generation Gas-Fueled Gas Turbines	Current Study	ND	11.1	ND	ND	ND
	Existing Data	168	15.0	29.7	5.1	4.4
	Combined Existing Data & Current Study	168	14.7	29.7	5.1	4.4
	EPA	169	17.2	47.0	5.7	0.26
Electricity Generation Distillate Oil-Fueled Gas Turbines	Current Study	ND	21.0	ND	7.0	14.3
	Existing Data	311	4.6	20.1	15.5	41.0
	Combined Existing Data & Current Study	311	11.1	20.1	13.0	33.1
	EPA	208	17.0	47.1	15.3	430S

ND - No data

S - Weight percent of sulfur in fuel

except in the case of SO_x emissions. The EPA emission factor for SO_x was calculated by assuming an average natural gas sulfur content of 4,600 $g/10^6 m^3$, and should be considered to be more representative than the SO_x emission factor calculated using two existing data points.

For electricity generation distillate oil-fueled gas turbines, the EPA emission factors are identical to the EPA emission factors for industrial distillate oil-fueled gas turbines. By comparison, emission factors from the current study for hydrocarbons are higher, and for particulates and SO_x are lower than the corresponding emission factors based on existing data. The lower particulate and SO_x emission factors obtained in this program are due to the low ash and sulfur content of the JP-5 fuel used in the five distillate oil-fueled gas turbines tested. Emission factors based on combined current study and existing data are in reasonably good agreement with the EPA emission factors for hydrocarbons and particulates. The SO_x emission factor based on current study and existing data corresponds to an average sulfur content of 0.08 weight percent for the distillate oils used as turbine fuel. The existing data NO_x emission factor is 50 percent higher than the EPA NO_x emission factor, and the existing data CO emission factor is 57 percent lower than the EPA CO emission factor. Again, the existing data emission factors for NO_x and CO should be considered more reliable, because the existing data base for NO_x and CO emissions is adequate and the quality of the data sources for the EPA emission factors cannot be readily assessed.

In Table 44, the emission factors for distillate oil reciprocating engines calculated from data collected in this program and the emission factors for reciprocating engines derived from existing data are compared with the EPA AP-42 emission factors (Reference 23). For industrial gas engines, the EPA emission factors were all based on the Southwest Research Institute (SWRI) data (References 11 and 16) and the data reported in the Standard Support Document and Environmental Impact Statement for Stationary Reciprocating Internal Combustion Engines (Reference 6), whereas the emissions data from the McGowin report (Reference 15) in addition to the above data sources have been used in the computation of the existing data emission factors. The EPA and existing data emission factors are almost identical, except in the case of CO emissions. The

TABLE 44. COMPARISON OF CRITERIA POLLUTANT EMISSION FACTORS FOR GAS AND DISTILLATE OIL ENGINES

Combustion Source Type	Data Source	Emission Factor, ng/J				
		NO_x	HC	CO	Part	SO_x
Industrial Gas Engines	Existing Data	1550	528	340	ND	ND
	EPA	1390	573	176	ND	0.26
Industrial Distillate Oil Engines	Existing Data	1390	51	266	ND	ND
	EPA	1420	115	312	102	430S
Electricity Generation Gas Engines	Existing Data	1550	528	340	ND	ND
	EPA	1230	17	47	5.7	0.26
Electricity Generation Distillate Oil Engines	Current Study	ND	56.9	ND	14.1	101
	Existing Data	1390	51	266	ND	ND
	Combined Existing Data and Current Study	1390	52	266	14.1	101
	EPA	1420	115	312	102	430S

ND - No data

S - Weight percent of sulfur in fuel

primary reasons for the lower EPA CO emission factor were the exclusion of a number of high CO emission data points reported in Reference 6 and the exclusion of the CO emission data in the McGowin report. As no explanation was given for the exclusion of these CO emission data points, the higher CO emission factor based on a larger number of data points is considered to be more representative of the emission characteristics of the total gas engine population.

In the current emissions assessment program, emissions from industrial and electricity reciprocating engines are evaluated together, because of the considerable over-lapping in size ranges for these two user sectors. The existing data emission factors for industrial and electricity generation gas engines are therefore identical. The EPA emission factors for industrial and electricity generation engines, however, are different. For electricity generation gas engines, the EPA NO_x emission factor is slightly lower than the EPA NO_x emission factor for industrial gas engines and the existing data NO_x emission factor for industrial/electricity generation gas engines. Comparison of the EPA emission factors presented in Tables 43 and 44 also shows that for hydrocarbon, CO and particulate emissions, EPA assumed identical emission factors for the electricity generation gas turbine and gas engine categories. This assumption is only reasonable when emissions data are not available, as in the case of particulate emissions from gas engines, because the emission characteristics for gas turbines and gas engines are quite different. For industrial/electricity generation gas engines, the existing data emission factors for NO_x, hydrocarbons and CO are considered to be more reliable than the corresponding EPA emission factors, especially because the existing emissions data base for these pollutants is adequate and contains over 70 data points. Particulate and SO_x emissions from gas engines are insignificant and the EPA emission factors for these pollutants may be used.

For distillate oil reciprocating engines, emissions from the industrial and electricity generation sources have been assumed to be identical by both EPA and in the evaluation of existing data. Adequate NO_x, hydrocarbon, and CO emissions data are available from the existing data base. The existing data NO_x and CO emission factors are about the same as the corresponding EPA emission factors. As noted in Table 44, the hydrocarbon emission factor obtained from the field tests in the current program is almost identical to the existing data hydrocarbon emission factor. Both the current study and existing data hydrocarbon emission factors are approximately half of the EPA hydrocarbon emission factor. For particulate and SO_x emissions, usable existing data are not available. The particulate emission factor, obtained from the eight field tests in the current program, is only 14 percent of the EPA particulate emission factor. The SO_x emission factor of 101 ng/J from the current study corresponds to a diesel fuel sulfur content of 0.24 percent. When there are differences in emission factors, emission factors based on combined current study and existing emissions data are considered to be more reliable, primarily because of the unknown quality of the data base for the EPA emission factors.

The significance of the emissions of criteria pollutants from the industrial and electricity generation internal combustion sources can be assessed using the source severity concept. The source severity concept has been discussed in Section 4.1, and detailed methods for the calculation of source severity factors are described in Appendix A. Basically, the source severity factor is defined as the ratio of the calculated maximum ground level concentration of the pollutant species to the level at which a potential environmental hazard exists. Source severity factors below 0.05 are deemed insignificant.

Source severity factors for the criteria pollutants have been calculated using emission factors based on combined current study and existing emissions data. EPA emission factors were only used for particulate and SO_x emissions from gas-fueled internal combustion sources. The calculated source severity factors, as presented in Table 45, indicate that the major pollutant from internal combustion turbines and reciprocating engines is nitrogen oxides. Significant amounts of hydrocarbons are also produced, especially in the case of reciprocating gas engines. For distillate oil reciprocating engines, source severity factors for SO_x emissions are greater than 0.05, indicating that these pollutants are of some concern and may require evaluation of control needs. In general, emissions of criteria pollutants from reciprocating engines are found to have greater potential environmental impact than emissions from turbines. With the combination of current study and existing emissions data, the data base for emissions of criteria pollutants from internal combustion sources is now adequate, and there is no need for additional tests.

TABLE 45. MEAN SOURCE SEVERITY FACTORS FOR CRITERIA POLLUTANTS

	Gas Turbine				Reciprocating Engine			
Pollutant	Industrial Gas	Industrial Distillate Oil	Elec. Gen. Gas	Elec. Gen. Distillate Oil	Industrial Gas	Industrial Distillate Oil	Elec. Gen. Gas	Elec. Gen. Distillate Oil
NO_x	0.52	0.82	0.17	0.32	5.66	5.09	7.09	6.35
HC	0.025	0.010	0.021	0.052	1.33	0.13	1.65	0.16
CO	0.0007	0.0014	0.0003	0.0002	0.0040	0.0032	0.0051	0.0040
Particulate	0.097	0.016	0.0019	0.0049	0.0055	0.015	0.0068	0.019
SO_x	<0.0001	0.029	<0.0001	0.0089	0.0002	0.078	0.0002	0.097

4.3.2 Emissions of SO_3, Particulate Sulfate, and Fine Particulates

Data on the composition of SO_x from combustion sources indicate that from 90 to 100 percent of emitted SO_x is sulfur dioxide. The remaining fraction of SO_x emissions is sulfur trioxide and its derivatives. The main sulfur trioxide derivative in effluent gases from combustion of distillate oil is sulfuric acid; metallic sulfates appear to be directly emitted only in trace quantities. Since sulfur trioxide combines with water vapor in the flue gas to form sulfuric acid vapor at temperatures below 400°C, reported values of sulfur trioxide emissions are generally equivalent to sulfuric acid emissions. As the flue gas is cooled below its dew point, a mist of sulfuric acid particles would begin to appear. Depending on the sampling temperature and procedure, the particulate sulfates collected would include all the metallic sulfates and some or all of the sulfuric acid aerosols.

For distillate oil-fueled gas turbines, it has been determined in the evaluation of existing data that an average of 3.81 percent of the sulfur content in the fuel is converted to SO_3. For distillate oil reciprocating engines, an average of 2.13 percent of the fuel sulfur content was found to be converted to SO_3, based on a single set of existing data. SO_3 emissions from gas-fueled internal combustion sources are insignificant because of the low sulfur content of natural gas.

In Table 46, the particulate sulfate emissions data obtained in this sampling and analysis program are presented. The particulate sulfate data reported here represent the total sulfate collected in the particulate filter, which includes metallic sulfates as well as a small amount of sulfuric acid aerosols. As noted in Table 46, only a small fraction of the sulfur in the fuel is converted to metallic sulfate.

As discussed previously, the Goksoyr-Ross controlled condensation train was used for the measurement of SO_3 emissions from three diesel engine sites. For Site No. 309-2, SO_3 was not detected from condensation coil rinse. This was probably because the condensation coil was maintained at a temperature above the dew point for H_2SO_4, and as a result none of the H_2SO_4 present was collected. For Sites Nos. 312-2 and 313-2, sufficient quantities of H_2SO_4 were collected, and it was determined that 0.99 and 1.07 percent of the fuel sulfur were converted to SO_3, respectively. The combined current study and existing

TABLE 46. SUMMARY OF EMISSION FACTOR DATA FOR PARTICULATE SULFATE FROM INTERNAL COMBUSTION SOURCES TESTED*

Combustion Source Type	Site No.	Emission Factor (ng/J)	$\frac{\text{Sulfur in Particulate } SO_4^=}{\text{Sulfur in Fuel}}$
Distillate Oil Fueled Gas Turbine	#112	0.335	0.731%
	#306	0.030	>0.476%
	#307	0.011	>0.175%
	#308	0.077	>1.222%
	Mean $\bar{x}$	0.113	0.651%
	$s(\bar{x})$	0.075	0.222%
	$ts(\bar{x})/\bar{x}$	2.1143	1.0835
Distillate Oil Reciprocating Engine	#309	0.383	0.308%
	#310	0.520	0.226%
	#311	0.971	0.423%
	#312	0.268	0.292%
	#313	0.468	0.420%
	Mean $\bar{x}$	0.522	0.334%
	$s(\bar{x})$	0.120	0.038%
	$ts(\bar{x})/\bar{x}$	0.6385	0.3190

* The particulate sulfate data reported include metallic sulfates and a small amount of condensed sulfuric acid aerosols.

$s(\bar{x})$ - Standard deviation of the mean.

$ts(\bar{x})/\bar{x}$ - Variability.

data indicate an average of 1.40 percent of the fuel sulfur is converted to SO_3 for diesel engines, with a variability $ts(\bar{x})/\bar{x}$ of 1.13. Because of the lower oxygen level in reciprocating engines, the percent of fuel sulfur converted to SO_3 is also lower for diesel engines than for distillate oil-fueled gas turbines.

The source severity factors for SO_3 emissions from electricity generation and industrial distillate oil turbines can be calculated by using a mean SO_x emission factor of 33.1 ng/J and an average conversion factor of 3.81 percent of sulfur content of the fuel to SO_3. The SO_3 emission factor calculated on this basis is 1.51 ng/J. The source severity factors for SO_3 are computed to be 0.056 and 0.18, respectively. This indicates that SO_3 emissions (in the form of sulfuric acid vapor and mist) from distillate oil-fueled gas turbines are potentially hazardous.

For distillate oil reciprocating engines, the general high sulfur content of diesel fuel would lead to higher SO_3 emissions. By assuming an average diesel fuel sulfur content of 0.24 percent and an average conversion factor of 1.40 percent of fuel sulfur to SO_3, the SO_3 emission factor for diesel engines is calculated to be 1.77 ng/J. Using this emission factor, the source severity factors for SO_3 emissions from electricity generation and industrial distillate oil reciprocating engines are computed to be 0.23 and 0.18, respectively.

In the evaluation of existing data, it has been determined that at least 90 percent of the particulate emissions from distillate oil turbines are submicron in size. For diesel engines, there is only limited amount of information on the size of the particulates emitted. The study conducted by Turley et al on a diesel engine, however, did indicate that approximately 75 percent by weight of the particulate emissions were less than 1 μm in size, and approximately 85 percent by weight of the particulate emissions were less than 3 μm in size (Reference 32). Thus, most of the particulate emissions from either distillate oil turbines or distillate oil engines can be considered as fine particulates.

4.3.3 Emissions of Trace Elements

Existing trace element data for oil-fueled internal combustion sources are generally inadequate. For distillate oil turbines, the existing data base for barium, beryllium, cadmium, lead, magnesium, manganese and vanadium emissions is adequate; however, the existing data base for the other trace elements is inadequate. For distillate oil engines, existing data on trace elements are not available. During the current program, trace element emissions in the stack gases were measured. Trace element content of the distillate oils was also determined and potential emissions calculated. In almost all cases the measured stack emissions were lower than the potential emissions.

Trace element measurements on the one gas turbine site (Site No. 110) showed emissions that could not be differentiated from the blank values in most cases. Even for those elements for which measured emissions were higher than blank values, these emission factors are considerably lower than the corresponding trace element emission factors for distillate oil-fueled gas turbines. Source severity factors for trace element emissions from gas-fueled gas turbines are well below 0.05. The conclusion is that emissions of trace elements from gas-fueled gas turbines are negligible when compared with total emissions of trace elements from all internal combustion sources. Additional measurements to improve the trace element data base for gas turbines are therefore unnecessary and estimates of trace element emission factors are of little use.

In Table 47, the trace elements emissions data for the distillate oil-fueled gas turbines tested in this program are presented. The emission factors presented are based primarily on the trace element content of the JP-5 fuel used at the test faciliites, and represent maximum potential emission rates. All trace elements that could have been emitted at any single site in amounts above 50 $\mu g/m^3$ (corrected to 15% O_2) are included in Table 47. Trace elements that are particularly hazardous (defined here as those with TLV $\leq$ 1 mg/m^3) are also included in Table 47. The emission factors show that the JP-5 fuel for Site No. 112 was contaminated with excessive amounts of barium, silicon, aluminum, magnesium, sodium, boron, and mercury. The emissions of these trace elements from Site No. 112 were considered to be outliers (using the method of Dixon described in Appendix A) and discarded in the calculation of the mean

TABLE 47 SUMMARY OF EMISSION FACTOR DATA FOR TRACE ELEMENTS FROM ELECTRICITY GENERATION DISTILLATE OIL-FUELED GAS TURBINES TESTED

Trace Element	Emission Factor, pg/J								
	Site 111	Site 112	Site 306	Site 307	Site 308	$\bar{x}$	$s(\bar{x})$	$\frac{ts(\bar{x})}{\bar{x}}$	$\bar{x}_u$
Pb	27	90	59	< 46	84	61	11	0.53	-
Ba	29	293	13	0.07	8	12.6	6.2	1.55	32
Sb*	< 5.2	< 5.2	< 2.0	< 2.1	14.5	5.8	2.3	1.09	12
Sn	2.7	42	115	3.6	9.6	35	21	1.71	94
Cd	2.9	3.8	1.0	0.3	5.8	2.8	0.98	0.99	5.5
Mo	1.9	2.8	3.6	2.9	6.7	3.6	0.82	0.64	-
Br	< 11.5	7.1	6.9	< 0.07	1.8	5.5	2.0	1.04	11
Se	2.3	< 5.2	1.9	0.3	1.9	2.3	0.81	0.96	4.6
As*	< 0.31	< 0.31	< 2.0	< 2.1	< 2.1	< 1.4	0.43	0.87	2.6
Zn	251	607	314	<201	96	294	86	0.81	533
Cu	65	649	649	649	879	578	136	0.65	-
Ni	67	94	1110	461	900	526	210	1.11	1110
Co	1.1	1.6	7.3	3.8	5.7	3.9	1.2	0.84	7.2
Fe	377	356	419	5	124	256	81	0.88	481
Mn	1487	8.6	188	335	4.9	405	277	1.90	1175
Cr	2.7	38	12	15	31	20	6.5	0.91	38
V	1.3	1.7	9.8	2.7	< 1.1	3.3	1.7	1.37	7.9

(Continued)

TABLE 47. (CONTINUED)

Trace Element	Emission Factor, pg/J								
	Site 111	Site 112	Site 306	Site 307	Site 308	$\bar{x}$	$s(\bar{x})$	$\frac{ts(\bar{x})}{\bar{x}}$	$\bar{x}_u$
Ca	314	460	565	<107	205	330	83	0.70	-
K	335	230	118	<107	135	185	43	0.65	-
P	184	92	230	< 46	80	127	35	0.76	223
Si	1256	110,970	533	< 30	482	575	254	1.40	1382
Al	57	293	< 59	< 50	90	64	8.9	0.44	-
Mg	<230	1068	152	< 63	61	127	41	1.02	256
Na	691	6280	<440	<460	768	590	82	0.44	-
B	82	3770	< 15	< 2.3	< 12	28	18	2.08	86
Be	< 0.044	0.11	< 0.12	< 0.14	< 0.38	0.16	0.06	1.02	0.32
Hg*	0.84	10	0.50	0.15	0.06	0.39	0.18	1.46	0.95

* Sb, As, and Hg emissions were determined by AA.

$\bar{x}$ = Mean emission factor

$s(\bar{x})$ = Standard deviation of the mean.

$ts(\bar{x})/\bar{x}$ = Variability.

$\bar{x}_u = \bar{x} + ts(\bar{x})$.

emission factors. For Site Nos. 111, 306 and 307, the manganese emission factors were higher than average values because organic manganese fuel additives were used in these three sites to suppress visible smoke emissions. With the possible exception of Site No. 307, emission factors for calcium, potassium and sodium all appear to be excessively high. As discussed in Section 4.1, a maximum limit of 0.5 ppm in fuel has been set for each of the critical trace elements: vanadium, combined sodium and potassium, calcium, and lead. The maximum limit of 0.5 ppm in fuel corresponds to a maximum emission factor of 112 ng/J. As noted in Table 47, the emission factors for calcium, potassium, and sodium have exceeded the 112 ng/J limit at all sites except possibly Site No. 307. On the other hand, the emission factors for lead and vanadium are well within the 112 ng/J limit for all the sites tested.

In Table 48, trace element emission factor data for distillate oil-fueled gas turbines based on combined current study and existing data are summarized. The calculated variability $ts(\bar{x})/\bar{x}$ presented in Tables 47 and 48 shows that the emissions data base is adequate for lead, barium, cadmium, molybdenum, copper, vanadium, calcium, potassium, aluminum, magnesium, sodium, and beryllium. For trace element emissions where the variability is greater than 0.7, the upper bound S_u for the mean source severity factors have also been calculated from $\bar{x}_u = \bar{x} + ts(\bar{x})$. The results of these source severity calculations show that among the trace element emissions, $S_u < 0.05$ for antimony, arsenic, boron, bromine, chromium, cobalt, iron, manganese, mercury, selenium, tin, and zinc. The emissions data base is therefore also adequate for these trace elements. Trace elements for which the emissions data base appears to be inadequate include nickel, phosphorus, and silicon. These are the trace element emissions with both the variability $ts(\bar{x})/\bar{x} > 0.7$ and $S_u > 0.05$. Additional emissions data for these trace elements can be obtained by analysis of fuel samples and field tests are not required.

The mean source severity factors for trace element emissions from electricity generation and industrial distillate oil turbines have been calculated using emission factors based on combined current study and existing emissions data. All trace elements with calculated mean source severity factors greater than 0.05 are presented in Table 49. These calculations indicate that among the trace elements, nickel, copper, and phosphorus are the principal pollutants.

TABLE 48. SUMMARY OF EMISSION FACTOR DATA FOR TRACE ELEMENTS FROM ELECTRICITY GENERATION DISTILLATE OIL-FUELED GAS TURBINES BASED ON COMBINED CURRENT STUDY AND EXISTING DATA

Trace Element	Mean Emission Factor $\bar{x}$ (pg/J)	$s(\bar{x})$ (pg/J)	$\frac{ts(\bar{x})}{\bar{x}}$	$\bar{x}_u$ (pg/J)
Pb	25	7.8	0.67	-
Ba	8.4	2.6	0.68	-
Cd	1.8	0.52	0.62	-
Mn	145	99	1.46	357
V	1.9	0.63	0.70	-
Mg	100	27	0.65	-
Be	0.14	0.03	0.46	-

$s(\bar{x})$ - Standard deviation of the mean.

$ts(\bar{x})/\bar{x}$ - Variability.

$\bar{x}_u = \bar{x} + ts(\bar{x})$. $\bar{x}_u$ values are not computed for trace element emissions with $ts(\bar{x})/\bar{x} \leq 0.7$.

TABLE 49. MEAN SOURCE SEVERITY FACTORS FOR TRACE ELEMENT EMISSIONS FROM DISTILLATE OIL-FUELED GAS TURBINES

Trace Element	Emission Factor (pg/J)	TLV (mg/m^3)	Mean Source Severity Factor: Elec. Gen. Distillate Oil-Fueled Gas Turbine	Mean Source Severity Factor: Industrial Distillate Oil-Fueled Gas Turbine
Cu	578	0.20	0.085	0.28
Ni	526	0.10	0.16	0.51
P	127	0.10	0.037	0.12

In Table 50, the trace element emissions data for the distillate oil engines tested in this program are presented. Again, the emission factors presented are based primarily on the trace element content of the diesel fuel used at the test facilities. All trace elements that could have been emitted at any single site in amounts above 50 $\mu g/m^3$ or are particularly hazardous (TLV $\leq$ 1 mg/m^3) are included in Table 50. The emissions data show that among the trace elements, sodium, nickel, copper, iron, and silicon were emitted in the largest quantities. The calculated variability $ts(\bar{x})/\bar{x}$ indicates that the emissions data base is adequate for lead, tin, cadmium, bromine, copper, nickel, manganese, potassium, phosphorus, aluminum, and mercury. For trace element emissions where the variability is greater than 0.7, the upper bound S_u for the mean source severity factors have been calculated. The S_u values calculated are for electricity generation distillate oil engines. The S_u values for industrial distillate oil engines would be proportionally lower. The results of these source severity calculations show that $S_u < 0.05$ for all the remaining trace elements. Since all trace element emissions either have their variability $ts(\bar{x})/\bar{x} < 0.7$ or $S_u < 0.05$, it is concluded that the data base for trace element emissions from distillate oil engines is adequate.

The impact of trace element emissions from distillate oil engines is assessed on the basis of the calculated mean source severity factors. All trace elements with calculated mean source severity factors greater than 0.05 are presented in Table 51. Among the trace elements, it is seen that nickel and copper emissions have the greatest potential impact, whereas phosphorus emissions are also of some concern.

The trace element emission factors for distillate oil-fueled gas turbines and distillate oil engines are compared in Table 52. It may be noted that for almost every trace element, the emission factors for the two internal combustion categories are about the same magnitude. The single exception is the difference between the emission factors for manganese. The manganese emission factor for distillate oil turbines is higher because of the use of organic manganese fuel additives at three of the five sites tested. The mean manganese emission factor, based on existing data and sites not employing manganese additives, is 13 pg/J for distillate oil turbines as compared to the manganese emission factor of 16 pg/J for distillate oil engines. The similarity between

TABLE 50. SUMMARY OF EMISSION FACTOR DATA FOR TRACE ELEMENTS FROM ELECTRICITY GENERATION DISTILLATE OIL ENGINES TESTED

Trace Element	Emission Factor, pg/J								
	Site 309	Site 310	Site 311	Site 312	Site 313	$\bar{x}$	$s(\bar{x})$	$\frac{ts(\bar{x})}{\bar{x}}$	$\bar{x}_u$
Pb	33	34	14	27	22	26	3.7	0.40	-
Ba	4.7	3.0	<13.8	12.9	33.3	14	5.4	1.11	28
Sb*	6.4	< 2.2	< 2.2	< 2.2	44.4	12	8.3	2.00	35
Sn	6.4	<11.3	7.1	10.0	<10.7	9.1	1.0	0.30	-
Cd	< 3.3	2.1	< 1.9	2.3	5.8	3.1	0.72	0.64	-
Mo	33	14	3	10	2	12	5.6	1.25	28
Br	5.2	2.2	< 6.7	2.0	4.1	4.0	0.89	0.61	-
Se	0.8	< 1.5	< 1.1	3.7	< 3.6	2.1	0.62	0.81	3.9
As*	< 2.2	< 2.2	< 2.2	< 2.2	< 2.2	2.2	0.01	0.01	-
Zn	147	15	88	377	63	178	56	0.88	334
Cu	644	533	422	244	422	453	66	0.41	-
Ni	955	422	622	444	375	563	106	0.52	-
Co	6.0	8.0	10.0	3.6	1.1	5.7	1.6	0.77	10.1
Fe	<488	38	211	<333	<555	325	94	0.80	585
Mn	20.9	26.6	5.3	19.8	8.0	16	3.9	0.68	-
Cr	33	47	13	31	6	26	7.4	0.79	46
V	0.78	2.44	0.51	0.76	0.25	0.95	0.39	1.13	2.02

(Continued)

TABLE 50. (CONTINUED)

Trace Element	Emission Factor, pg/J								
	Site 309	Site 310	Site 311	Site 312	Site 313	$\bar{x}$	$s(\bar{x})$	$\frac{ts(\bar{x})}{\bar{x}}$	$\bar{x}_u$
Ca	<178	73	89	133	710	237	120	1.41	569
K	<344	134	97	175	146	179	43	0.67	-
P	< 93	133	100	40	120	97	16	0.46	-
Si	<733	<191	189	229	165	301	108	1.00	602
Al	62	100	69	< 40	58	66	9.7	0.41	-
Mg	< 91	35	< 5	44	37	44	15	0.95	85
Na	1110	511	5330	<287	<889	1625	937	1.60	4226
B	< 33	11	< 5.1	< 4.2	2.7	11	5.7	1.41	27
Be	< 0.052	0.031	< 0.018	< 0.009	0.029	0.028	0.007	0.73	0.048
Hg*	0.07	0.20	0.16	0.16	0.09	0.13	0.02	0.51	-

* Sb, As, and Hg emissions were determined by AA.

$\bar{x}$ - Mean emission factor.

$s(\bar{x})$ - Standard deviation of the mean.

$ts(\bar{x})/\bar{x}$ - Variability.

$\bar{x}_u = \bar{x} + ts(\bar{x})$.

TABLE 51. MEAN SOURCE SEVERITY FACTORS FOR TRACE ELEMENT EMISSIONS FROM DISTILLATE OIL ENGINES

Trace Element	Emission Factor (pg/J)	TLV (mg/m^3)	Mean Source Severity Factor	
			Elec. Gen. Distillate Oil Engine	Industrial Distillate Oil Engine
Cu	453	0.20	0.23	0.20
Ni	563	0.10	0.60	0.48
P	97	0.10	0.10	0.082

the emission factors is the result of the similarity between the trace element content of turbine and diesel fuels.

4.3.4 Emissions of Organics and Polycyclic Organic Matter

Analysis of the organic samples have indicated that organic emissions from internal combustion sources consist mainly of saturated and unsaturated aliphatic and aromatic hydrocarbons. The most prevalent organic species present were straight chain and branched chain saturated hydrocarbons, with MATE values in the 100 to 1000 mg/m^3 range. Substituted benzenes, the second most abundant organic species emitted, have MATE values greater than 100 mg/m^3. The mean source severity factors calculated using these MATE values indicate that emissions of these organic species from internal combustion sources are environmentally insignificant as $S < 0.001$ in all cases.

POM emissions from the one gas-fueled gas turbine and the five distillate oil-fueled gas turbines tested could not be differentiated from the blank values and are therefore considered insignificant. POM emissions data from the eight distillate oil engines tested are presented in Table 53. Of the POM's, the naphthalenes and substituted naphthalenes were emitted in the largest quantities. POM compounds known to be carcinogenic, such as benzo(a)-pyrene and dibenz(a,h)anthracene, were not detected. For the Level II organic analysis performed, the detection limit has been established at 0.05 $\mu g/m^3$.

TABLE 52. COMPARISON OF TRACE ELEMENT EMISSION FACTORS FOR DISTILLATE OIL-FUELED GAS TURBINES AND DISTILLATE OIL ENGINES

Trace Element	Mean Emission Factor, pg/J Distillate Oil Fueled Gas Turbine	Mean Emission Factor, pg/J Distillate Oil Reciprocating Engine
Aluminum	64	66
Antimony	9.4	12
Arsenic	2.1	2.2
Barium	8.4	14
Beryllium	0.14	0.03
Boron	28	11
Bromine	1.8	4.0
Cadmium	1.8	3.1
Calcium	330	237
Chromium	20	26
Cobalt	3.9	5.7
Copper	578	453
Iron	256	325
Lead	25	26
Magnesium	100	44
Manganese	145	16
Mercury	0.39	0.13
Molybdenum	3.6	12.5
Nickel	526	564
Phosphorus	127	97
Potassium	185	179
Selenium	2.3	2.1
Silicon	575	301
Sodium	590	1625
Tin	35	9.1
Vanadium	1.9	0.95
Zinc	294	178

TABLE 53. SUMMARY OF POM EMISSION FACTOR DATA FROM ELECTRICITY GENERATION DISTILLATE OIL ENGINES TESTED*

Compound	Emission Factor (pg/J)											
	Site 309	Site 310	Site 311	Site 312	Site 313	Site 309-2	Site 312-2	Site 313-2	$\bar{x}$	$s(\bar{x})$	$\frac{ts(\bar{x})}{\bar{x}}$	$\bar{x}_u$
Naphthalene	8.4	12.7	35.8	-	1.9	124.5	34.5	131.9	43.7	19.0	1.03	88.8
Methyl Naphthalene	-	15.5	-	-	-	336.2	339.2	353.7	130.6	62.3	1.13	277.8
C_2 Substituted Naphthalene	15.6	8.5	63.7	-	-	369.5	474.9	653.4	198.2	92.5	1.10	417.0
C_3 Substituted Naphthalene	4.2	2.8	-	-	-	460.7	158.3	402.8	128.6	69.1	1.27	292.0
C_4 Substituted Naphthalene	-	-	-	-	-	249.7	-	16.8	33.3	31.0	2.20	106.6
C_5 Substituted Naphthalene	-	-	-	-	-	87.6	-	-	11.0	11.0	2.37	36.8
Biphenyl	1.0	4.2	10.0	-	9.5	-	-	21.6	5.8	2.7	1.10	12.2
Methyl Biphenyl	-	-	-	-	-	-	-	167.8	21.0	21.0	2.37	70.6
C_3 Biphenyl	-	-	-	-	-	11.7	-	-	1.5	1.5	2.37	4.9
Dibenzothiophene	2.6	1.4	-	-	-	-	-	-	0.50	0.35	1.64	1.3
Methyl Dibenzothiophene	-	0.57	-	-	-	-	-	-	0.071	0.071	2.37	0.24
Phenanthrene/Anthracene	4.2	2.1	-	-	-	68.6	22.6	55.1	19.1	9.8	1.21	42.2
Methyl Phenanthrene	10.4	5.6	59.7	40.9	95.2	62.8	13.1	-	36.0	12.1	0.80	64.6
Dimethyl Phenanthrene	2.1	0.6	23.9	24.4	36.8	-	-	-	10.8	5.3	1.13	23.5
Trimethyl Phenanthrene	-	-	-	6.4	9.5	-	-	-	2.0	1.3	1.59	5.1
Ethyl Fluorene	-	-	-	-	-	17.5	-	-	2.2	2.2	2.37	7.4

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*Emissions below detection limits or cannot be distinguished from blank values are indicated by -. For Site Nos. 309, 310, 311, 312 and 313, detection limits for POM compounds were approximately 0.05 ng/J (0.08 $\mu g/m^3$). For Site Nos. 309-2, 312-2 and 3-312, detection limits for POM compounds were approximately 0.03 ng/J (0.05 $\mu g/m^3$).

All phenanthrene compounds could also be anthracenes.

Using this detection limit, the calculated source severity factor for benzo(a)-pyrene emissions from electricity generation distillate oil engines is less than 0.2.

The impact of the POM emissions found is assessed in Table 54 by the use of the MATE values, which are equivalent to TLV's and have been previously discussed in the evaluation of existing emissions data. The mean source severity factors calculated using the MATE values indicate that the POM emissions from distillate oil engines were several orders of magnitude below levels of concern.

The insignificance of the POM emissions from gas turbines and reciprocating engines is expected because of the high hydrogen to carbon ratio of the fuels used and the high oxygen level in the combustion gases. Pyrolytic conditions, which favor the formation of POM's, are seldom encountered in these internal combustion systems.

4.3.5 Summary of Status of Emissions Data Base

Based on the analysis of the TRW/GCA test results and the existing emissions data base, the status of the emissions data base for internal combustion sources can be summarized as follows:

- Emissions of criteria pollutants are now adequately characterized. There is no need for additional tests.
- For distillate oil-fueled gas turbines, the existing data base for SO_3 emissions is adequate. For distillate oil reciprocating engines, the data base for SO_3 emissions could be improved by additional field tests.
- Trace element emissions from gas-fueled internal combustion sources are insignificant. For distillate oil engines, the data base for trace element emissions is adequate. For distillate oil-fueled gas turbines, the data base appears to be inadequate for the following trace elements: nickel, phosphorus, and silicon. However, additional emissions data for these trace elements may be obtained by analysis of fuel samples, because trace element emissions from distillate oil-fueled gas turbines have been calculated primarily from fuel trace element contents. There is no need for Level II or additional Level I tests.
- Emissions of organics and POM's are either environmentally insignificant or at levels too low to be detected.

TABLE 54. MEAN SOURCE SEVERITY FACTORS FOR POM EMISSIONS FROM ELECTRICITY GENERATION DISTILLATE OIL ENGINES

Compound	Mean Emission Factor (pg/J)	MATE[*] Value (mg/m^3)	Mean Source Severity Factor S
Naphthalene	43.7	50	<0.0001
Methyl Naphthalene	130.6	230	<0.0001
C$_2$ Substituted Naphthalene[†]	198.2	230	<0.0001
C$_3$ Substituted Naphthalene[†]	128.6	230	<0.0001
C$_4$ Substituted Naphthalene[†]	33.3	230	<0.0001
C$_5$ Substituted Naphthalene[†]	11.0	230	<0.0001
Biphenyl	5.8	1.0	0.0006
Methyl Biphenyl[‡]	21.0	1.0	0.0022
C$_3$ Biphenyl[‡]	1.5	1.0	0.0002
Dibenzothiophene	0.50	23	<0.0001
Methyl Dibenzothiophene[**]	0.071	23	<0.0001
Phenanthrene/Anthracene	19.1	1.6	0.0013
Methyl Phenanthrene/Anthracene	36.0	30	0.0001
Dimethyl Phenanthrene/Anthracene[††]	10.8	30	<0.0001
Trimethyl Phenanthrene/Anthracene[††]	2.0	30	<0.0001
Ethyl Fluorene[‡‡]	2.2	90	<0.0001

[*] MATE values are obtained from Reference 29.

[†] The MATE values for C$_2$, C$_3$, C$_4$ and C$_5$ substituted naphthalenes are assumed to be the same as that for dimethyl naphthalene.

[‡] The MATE values for methyl and C$_3$ biphenyl are assumed to be the same as that for biphenyl.

[**] The MATE value for methyl dibenzothiophene is assumed to be the same as that for dibenzothiophene.

[††] The MATE values for dimethyl and trimethyl phenanthrene are assumed to be the same as that for methyl phenanthrene.

[‡‡] The MATE for ethyl fluorene is assumed to be the same as that for fluoranthene.

5. TOTAL EMISSIONS

Based on the results of current sampling and analysis efforts and the existing emissions data base, estimates of current national emissions and projected 1985 national emissions from electricity generation and industrial gas turbines and reciprocating engines have been made by using current and predicted future fuel consumption rates.

5.1 CURRENT AND FUTURE FUEL CONSUMPTION

Current fuel consumption data are available for electricity generation internal combustion sources but not for industrial internal combustion sources. The Federal Power Commission (FPC) has published data showing that to produce electric energy in 1976, internal combustion plants owned by utilities burned 6.625×10^6 m^3 of oil (259.42×10^{15} J) and 4.132×10^9 m^3 of gas (157.48×10^{15}J) (Reference 4). For the same year, the National Electric Reliability Council (NERC) estimated total fuel consumption of 5.827×10^6 m^3 of oil (228.40×10^{15} J) and 3.466×10^9 m^3 of gas (132.09×10^{15} J) for utility combustion and combined cycle turbines (Reference 5). The fuel consumption for internal combustion engines can therefore be estimated from the above figures by difference. The 1976 fuel consumption were 20.79×10^{15} J for electricity generation distillate oil reciprocating engines, and 25.39×10^{15} J for electricity generation gas reciprocating engines.

For 1978, NERC estimated total fuel consumption of 8.598×10^6 m^3 of oil (337.81×10^{15} J) and 3.927×10^9 m^3 of gas (149.52×10^{15} J) for utility combustion and combined cycle turbines (Reference 5). The 1978 fuel consumption for electricity generation reciprocating engines can be assumed to be equal to the 1976 figures, as reciprocating engine generating capacity for the two years are about equal.

For industrial internal combustion sources, detailed fuel consumption data for 1971 are available (Reference 15). The major uses of industrial gas turbines and reciprocating engines are transmission of oil and natural gas in pipelines, natural gas processing and production, and crude oil production. The 1978 fuel consumption for these combustion source categories are therefore estimated from the 1971 fuel consumption and using the ratios of the domestic natural gas and crude oil production figures for these two years (References 33, 34 and 35). The 1971 estimates by McGowin, however, did not provide fuel consumption data for industrial distillate oil-fueled gas turbines. Utilizing data contained in the National Emissions Data System (NEDS), Dykema and Kemp have estimated the 1976 and 1980 fuel consumption for industrial oil-fueled gas turbines (Reference 36). The NEDS data base is, in general, incomplete but nevertheless is useful as a supplementary source of information. Based on the McGowin and Dykema and Kemp data, the 1978 fuel consumption rates for the four industrial internal combustion sources are estimated to be: 10.97×10^{15} J for distillate oil-fueled gas turbines, 438.02×10^{15} J for gas-fueled gas turbines, 61.93×10^{15} J for distillate oil reciprocating engines, and 1003.92×10^{15} J for gas reciprocating engines.

Prediction of fuel use trends by internal combustion sources from present time to 1985 is subject to many uncertainties. For electricity generation distillate oil and gas turbines, the National Electric Reliability Council (NERC) has estimated fossil fuel requirements for the years 1977 - 1986 (Reference 5). According to the NERC estimates, the fossil fuel requirements for 1985 will be: 8.204×10^6 m^3 of oil and 0.641×10^9 m^3 of gas for combustion turbines, and 9.657×10^6 m^3 of oil and 1.681×10^9 m^3 of gas for combined cycle turbines. These figures are equivalent to a projected 1985 total fuel consumption of 702.85×10^{15} J for oil-fueled electricity generation turbines and 88.49×10^{15} J for gas-fueled electricity generation turbines. The figures also represent a 108.1 percent increase and 40.8 percent decrease in fuel consumption for the oil-fueled and gas-fueled gas turbines from 1978 to 1985. The increase in oil consumption will be mostly due to the fuel requirements for the operation of combined cycle turbines, used for base load rather than peaking service.

For electricity generation reciprocating engines, the Federal Power Commission reported that as of April 1, 1976, a net of 112,000 KW of diesel and dual-fuel generating capacity were scheduled to be installed in the 1976 — 1985 period (Reference 10). This added capacity represents only a 2.1 percent increase over the 1976 generating capacity. Assuming that the fuel requirement would also increase by 2.1 percent during the same period, the fuel consumption for distillate oil reciprocating engines would increase by 37.2 percent from 1978 to 1985 if the fuel consumption for gas reciprocating engines would decrease by 40.8 percent, the same as that for gas-fueled turbines during the same period. On this basis, the 1985 fuel consumption would be 42.57×10^{15} J for distillate oil reciprocating engines and 15.03×10^{15} J for gas reciprocating engines. The estimated 1978 and 1985 fuel consumption rates for electricity generation internal combustion sources are summarized and compared in Table 55.

The projected 1985 fuel consumption rates for industrial internal combustion sources were estimated on the basis of the 1985 domestic natural gas (including a small percentage of SNG) and crude oil supply rates. The estimates

TABLE 55. 1978 AND PROJECTED 1985 FUEL CONSUMPTION FOR ELECTRICITY GENERATION INTERNAL COMBUSTION SOURCES

Combustion Source Category	Fuel Consumption, 10^{15} J 1978	 1985	Percent Change 1978 - 1985
Distillate Oil Fueled Gas Turbines*	337.81	702.84	+108.1%
Gas Fueled Gas Turbines	149.52	88.49	-40.8%
Distillate Oil Reciprocating Engines	31.02	42.57	+37.2%
Gas Reciprocating Engines	25.39	15.03	-40.8%
Total	543.74	848.94	+56.1%

*The estimated 1985 fuel consumption for distillate oil turbines includes approximately 6.6 percent residual oil fuel.

discussed in this report are obtained from the two latest studies by the Bureau of Mines and the Federal Energy Commission (References 34 and 35). The U.S. Department of the Interior, Bureau of Mines (BOM) has published estimates of energy use trends to the years 1980, 1985 and 2000. Their projections are "based essentially on the evaluation of BOM fuels data" and the assumption that "existing patterns of resource utilization will continue." BOM projections for domestic natural gas and crude oil production for the year 1985 are presented in Table 56 along with the Federal Energy Administration (FEA) projections.

The method used by the FEA is briefly described below:

> "The Project Independence Evaluation System (PIES) is a model of the technologies, leadtimes, costs and geographical locations which affect energy commodities from the point of discovery, through production, transportation, conversion to more useful forms, and ultimately consumption by all sectors of the economy. Consumption (final demand) for a particular fuel depends on prices for that fuel, the prices of substitute fuels, the general level of economic activity, and the ability of consumers and capital stocks to adjust to these factors. For each year of analysis, FEA forecasts the demand for refined petroleum products, natural gas, electricity, and coal. These fuel demands are made for each Census region and for each end-use consuming sector — residential and commercial, industrial, and transportation. These demand forecasts are based on estimated prices and vary as prices change.
>
> Energy supply is estimated separately for oil, natural gas, and coal. For each fuel, many different regions are separately evaluated to assess the differences between OCS and Alaskan oil or Appalachian and Western coal. For each region and fuel, reserve estimates are combined

TABLE 56. PROJECTED 1985 DOMESTIC NATURAL GAS AND CRUDE OIL PRODUCTION

Fuel	1985 Production, 10^{15} J		Percent Change 1974 - 1985	
	BOM	FEA*	BOM	FEA
Domestic Natural Gas	20,278	24,248	-9.67%	+8.02%
Domestic Crude Oil	31,557	29,302	+42.04%	+31.89%

*Based on business as usual supply and demand cases and price of $13 per barrel for imported oil.

> with the technologies and costs of finding and producing these fuels to estimate the cost of increasing supply. Major improvements have been made in the oil and gas models to estimate drilling patterns, link finding rates and enhanced recovery directly to revised reserve estimates, and account for changes in the depletion allowance. The coal supply estimates distinguish between various sulfur and Btu contents.
>
> The PIES then attempts to match these energy demands as a function of fuel, sector, and price with the available supply in the regions which can supply these needs at the lowest price to find a balance or equilibrium. If supply is not available to satisfy the specific demands in an area, the prices are allowed to vary until supply and demand are brought into balance."

FEA conducted the above analyses for three imported oil prices ($8, $13 and $16 per barrel) and four alternative energy strategies (business as usual, accelerated supply, accelerated conservation, and a combination of accelerated supply and conservation). The base case of business as usual supply and demand and price of $13 per barrel for imported oil is used in this report.

The FEA and BOM estimates differ in two important areas. First with regard to natural gas production, BOM predicts a 9.7 percent decrease while FEA predicts an 8.0 percent increase for the 1974 – 1985 period. The second major difference is that BOM predicts a higher 1985 domestic crude oil production rate than FEA. The total fuel production rate from domestic natural gas and crude oil of $51{,}835 \times 10^{15}$ J as predicted by BOM, however, is only slightly different from the $53{,}550 \times 10^{15}$ J figure predicted by FEA.

Utilizing the 1985 domestic natural gas and crude oil production figures predicted by BOM or FEA, the 1985 fuel consumption rates for industrial internal combustion sources are estimated. The assumptions used are that fuel consumption rates for gas fueled turbines and reciprocating engines are proportional to domestic natural gas production and that fuel consumption rates for oil fueled turbines and reciprocating engines are proportional to domestic crude oil production. An exception is that fuel consumed by gas reciprocating engines for crude oil production is assumed to be proportional to the domestic crude oil production rate. The estimated 1985 fuel consumption rates for industrial internal combustion sources are presented in Table 57, along with the 1978 figures for comparison.

TABLE 57. 1978 AND PROJECTED 1985 FUEL CONSUMPTION FOR INDUSTRIAL INTERNAL COMBUSTION SOURCES

Combustion Source Category	Fuel Consumption, 10^{15} J			Percent Change 1978 - 1985	
	1978	1985 BOM	1985 FEA	BOM	FEA
Distillate Oil-Fueled Gas Turbines	10.97	13.90	12.91	+26.7%	+17.7%
Gas-Fueled Gas Turbines	438.02	397.23	475.00	-9.3%	+8.4%
Distillate Oil Reciprocating Engines	61.93	78.46	72.86	+26.7%	+17.7%
Gas Reciprocating Engines	1,003.92	926.54	1,092.78	-7.7%	+8.9%
Total	1,514.84	1,416.13	1,653.55	-6.5%	+9.2%

5.2 CURRENT NATIONWIDE EMISSIONS

Total 1978 national emissions from electricity generation and industrial internal combustion sources were determined based on combined current study and existing data emission factors and the estimated 1978 fuel consumption rates discussed in the previous section. Nationwide emission totals for the criteria pollutants are presented in Table 58. Particulate and SO_x emissions from internal combustion sources are relatively small and amount to less than 0.5 percent of emissions of these pollutants from all stationary sources. Emissions of NO_x, hydrocarbons, and CO from internal combustion courses, however, are more significant. NO_x, hydrocarbon, and CO emissions from internal combustion sources account for approximately 20 percent, 9 percent, and 1 percent of the emissions of these pollutants from all stationary sources. Of the NO_x, hydrocarbon, and CO emissions from internal combustion sources, more than 80 percent are contributed by the industrial reciprocating gas engine cateogry.

TABLE 58. CURRENT NATIONWIDE EMISSIONS OF CRITERIA POLLUTANTS FROM ELECTRICITY GENERATION AND INDUSTRIAL INTERNAL COMBUSTION SOURCES

Combustion Source Category	Emissions, Mg/year				
	NO_x	HC	CO	Part	SO_x
Electricity Generation					
Distillate Oil-Fueled Gas Turbines	105,000	5,900	14,800	4,400	11,200
Gas-Fueled Gas Turbines	25,200	3,500	9,700	800	40
Distillate Oil Engines	43,200	1,600	8,300	400	3,100
Gas Engines	39,300	13,400	8,600	100	10
Subtotal	212,700	24,400	41,400	5,700	14,350
Industrial					
Distillate Oil-Fueled Gas Turbines	2,300	40	1,100	100	400
Gas-Fueled Gas Turbines	56,800	3,800	21,400	2,200	100
Distillate Oil Engines	86,200	3,200	16,500	900	6,300
Gas Engines	1,555,000	530,000	341,300	5,700	300
Subtotal	1,700,300	537,040	380,300	8,900	7,100
Total, Internal Combustion	1,913,000	561,400	421,700	14,600	21,500

Current trace element emissions from internal combustion sources are summarized in Table 59. Emissions from gas fueled turbines and engines are negligible relative to oil fueled sources and are not reported. The estimated trace element emissions represent about 25 to 40 percent of the total particulate emissions, indicating the completeness of combustion for these sources categories. Total quantities of trace elements emitted are less than those from residential sources and should be negligible when compared with trace element emissions from coal-fired combustion sources.

TABLE 59. CURRENT NATIONWIDE EMISSIONS OF TRACE ELEMENTS FROM ELECTRICITY GENERATION AND INDUSTRIAL INTERNAL COMBUSTION SOURCES*

Trace Element	Emissions, Mg/year			
	Elec. Gen. Distillate Oil-Fueled Gas Turbines	Elec. Gen. Distillate Oil Engines	Industrial Distillate Oil-Fueled Gas Turbines	Industrial Distillate Oil Engines
Aluminum	22	2.0	0.70	4.1
Antimony	3.2	0.36	0.10	0.71
Arsenic	0.72	0.069	0.023	0.14
Barium	2.8	0.42	0.092	0.84
Beryllium	0.048	0.0008	0.0016	0.0017
Boron	9.4	0.35	0.30	0.69
Bromine	0.61	0.12	0.020	0.25
Cadmium	0.62	0.096	0.020	0.19
Calcium	110	7.3	3.6	15
Chromium	6.7	0.80	0.22	1.6
Cobalt	1.3	0.18	0.043	0.35
Copper	200	14	6.3	28
Iron	87	10	2.8	20
Lead	8.4	0.81	0.27	1.6
Magnesium	34	1.4	1.1	2.7
Manganese	49	0.51	1.6	1.0
Mercury	0.13	0.0041	0.0043	0.0082
Molybdenum	1.2	0.39	0.039	0.77
Nickel	180	17	5.8	35
Phosphorus	43	3.0	1.4	6.0
Potassium	63	5.6	2.0	11
Selenium	0.79	0.066	0.026	0.13
Silicon	190	9.3	6.3	19
Sodium	200	50	6.5	100
Tin	12	0.28	0.38	0.56
Vanadium	0.66	0.029	0.021	0.059
Zinc	99	5.5	3.2	11

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*All trace elements that showed a potential concentration above 50 $\mu g/m^3$ at any site or are particularly hazardous (TLV <1 mg/m^3).

Emissions of polycyclic organic matter (POM) from oil fueled reciprocating engines are summarized in Table 60. POM emissions from gas and oil fueled turbines were not detected. Total POM emissions from distillate oil engines were estimated to be 60 Mg (megagrams) per year. As discussed previously, POM compounds known to be carcinogenic were not detected.

5.3 FUTURE NATIONWIDE EMISSIONS

Based on the porjected 1985 fuel consumption for internal combustion sources discussed in Section 5.1, future nationwide emissions from these combustion categories were estimated. Estimated future nationwide emissions

TABLE 60. CURRENT NATIONWIDE EMISSIONS OF POLYCYCLIC ORGANIC MATTER FROM ELECTRICITY GENERATION AND INDUSTRIAL INTERNAL COMBUSTION SOURCES

	Emissions, Mg/year	
Compound	Elec. Gen. Distillate Oil Engines	Industrial Distillate Oil Engines
Naphthalene	1.4	2.7
Methyl Naphthalene	4.1	8.1
C_2 Substituted Naphthalene	6.1	12.3
C_3 Substituted Naphthalene	4.0	8.0
C_4 Substituted Naphthalene	1.0	2.1
C_5 Substituted Naphthalene	0.34	0.68
Biphenyl	0.18	0.36
Methyl Biphenyl	0.65	1.3
C_3 Biphenyl	0.046	0.093
Dibenzothiophene	0.016	0.031
Methyl Dibenzothiophene	0.002	0.0044
Phenanthrene/Anthracene	0.59	1.2
Methyl Phenanthrene/Anthracene	1.1	2.2
Dimethyl Phenanthrene/Anthracene	0.34	0.67
Trimethyl Phenanthrene/Anthracene	0.062	0.12
Ethyl Fluorene	0.068	0.14

for the criteria pollutants, trace elements, and POM's are presented in Tables 61, 62, and 63. For the criteria pollutants, the 1978 and projected 1985 emissions are approximately equal except for SO_x. The projected 1985 SO_x emissions from internal combustion sources represent a 69 percent increase over the 1978 SO_x emissions, because of the increase in fuel consumption for electricity generation distillate oil-fueled gas turbines. The total 1985 SO_x emissions, however, will still be insignificant. Total 1985 trace element emissions from internal combustion sources represent a two-fold increase from the 1978 trace element emissions. This again will be the result of increased fuel consumption for electricity generation distillate oil-fueled gas turbines.

TABLE 61. PROJECTED 1985 NATIONWIDE EMISSIONS OF CRITERIA POLLUTANTS FROM ELECTRICITY GENERATION AND INDUSTRIAL INTERNAL COMBUSTION SOURCES

Combustion Source Category	Emissions, Mg/year				
	NO_x	HC	CO	Part	SO_x
Electricity Generation					
Distillate Oil-Fueled Gas Turbines	218,400	12,300	30,800	9,100	23,300
Gas-Fueled Gas Turbines	14,900	2,100	5,700	500	20
Distillate Oil Engines	59,300	2,200	11,300	600	4,300
Gas Engines	23,300	7,900	5,100	100	4
Subtotal	315,900	24,500	52,900	10,300	27,600
Industrial					
Distillate Oil-Fueled Gas Turbines	2,900	50	1,400	200	500
Gas-Fueled Gas Turbines	51,500	3,400	19,400	2,000	100
Distillate Oil Engines	109,200	4,100	20,900	1,100	7,900
Gas Engines	1,435,200	489,200	315,000	5,300	200
Subtotal	1,598,800	496,800	356,700	8,600	8,700
Total, Internal Combustion	1,914,700	521,300	467,200	18,900	36,300

TABLE 62. PROJECTED 1985 NATIONWIDE EMISSIONS OF TRACE ELEMENTS FROM ELECTRICITY GENERATION AND INDUSTRIAL INTERNAL COMBUSTION SOURCES

Trace Element	Emissions, Mg/year			
	Elec. Gen. Distillate Oil-Fueled Gas Turbines	Elec. Gen. Distillate Oil Engines	Industrial Distillate Oil-Fueled Gas Turbines	Industrial Distillate Oil Engines
Aluminum	45	2.8	0.89	5.2
Antimony	6.6	0.49	0.13	0.90
Arsenic	1.5	0.094	0.030	0.17
Barium	5.9	0.58	0.12	1.1
Beryllium	0.10	0.0012	0.0020	0.0022
Boron	20	0.48	0.39	0.88
Bromine	1.3	0.17	0.025	0.32
Cadmium	1.3	0.13	0.025	0.24
Calcium	230	10	4.6	19
Chromium	14	1.1	0.27	2.0
Cobalt	2.7	0.24	0.054	0.45
Copper	410	19	8.0	36
Iron	180	14	3.6	26
Lead	18	1.1	0.35	2.0
Magnesium	70	1.9	1.4	3.4
Manganese	100	0.69	2.0	1.3
Mercury	0.27	0.0057	0.0054	0.010
Molybdenum	2.5	0.53	0.050	0.98
Nickel	370	24	7.3	44
Phosphorus	89	4.1	1.8	7.6
Potassium	130	7.6	2.6	14
Selenium	1.6	0.091	0.032	0.17
Silicon	400	13	8.0	24
Sodium	410	69	8.2	130
Tin	24	0.39	0.48	0.71
Vanadium	1.4	0.040	0.027	0.074
Zinc	210	7.6	4.1	14

TABLE 63. PROJECTED 1985 NATIONWIDE EMISSIONS OF POLYCYCLIC ORGANIC MATTER FROM ELECTRICITY GENERATION AND INDUSTRIAL INTERNAL COMBUSTION SOURCES

	Emissions, Mg/year	
Compound	Elec. Gen. Distillate Oil Engines	Industrial Distillate Oil Engines
Naphthalene	1.9	3.4
Methyl Naphthalene	5.6	10
C_2 Substituted Naphthalene	8.4	16
C_3 Substituted Naphthalene	5.5	10
C_4 Substituted Naphthalene	1.4	2.6
C_5 Substituted Naphthalene	0.47	0.86
Biphenyl	0.25	0.46
Methyl Biphenyl	0.89	1.6
C_3 Biphenyl	0.064	0.12
Dibenzothiophene	0.021	0.039
Methyl Dibenzothiophene	0.003	0.006
Phenanthrene/Anthracene	0.81	1.5
Methyl Phenanthrene/Anthracene	1.5	2.8
Dimethyl Phenanthrene/Anthracene	0.46	0.85
Trimethyl Phenanthrene/Anthracene	0.085	0.16
Ethyl Fluorene	0.094	0.17

The total 1985 POM emissions from internal combustion sources will amount to 78 Mg per year, or approximately a 30 percent increase over the 1978 POM emissions. This will still be a negligible fraction of the total POM emissions from stationary sources, and the POM's emitted from internal combustion sources will be relatively harmless compounds, such as naphthalene, alkyl naphthalene, and alkyl phenanthrenes, with typical MATE values in the 1 to 230 mg/m^3 range.

During recent years, fuels of other types have been evaluated for use in gas turbine power generation. Specifically, methanol has been demonstrated as a viable replacement fuel for gas turbines, based both on excellent performance and low emissions. In one series of tests, NO_x emissions from methanol fuel were found to be 74 percent less than with No. 2 oil, and CO emissions from methanol fuel were only slightly higher compared to No. 2 Oil (Reference 37). On the negative side, today's methanol production will only supply a very small fraction of the current gas turbine fuel requirements. If methanol supply can be increased substantially while at the same time the methanol cost becomes competitive with No. 2 oil, then methanol can be an alternative fuel for gas turbines in the future. For the 1978 - 1985 period, however, gas and oil are expected to remain as the critical fuels for gas turbines and reciprocating engines (Reference 5).

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APPENDIX A

APPENDIX A

CRITERIA FOR EVALUATING THE ADEQUACY OF EXISTING EMISSIONS DATA FOR CONVENTIONAL STATIONARY COMBUSTION SYSTEMS

A major task in the present program was the identification of gaps and inadequacies in the existing emissions data base for conventional stationary combustion systems. The output from this effort will be used in the planning and performance of a combined field and laboratory program as required to complete adequate emissions assessment for each of the combustion source types.

The criteria for assessing the adequacy of emissions data are developed by considering both the reliability of the data and the variability of the data. The general approach is to utilize a three-step process as described below. This approach is applicable to the evaluation of the existing emissions data as well as emissions data collected during the course of this program.

STEP 1

In the first step of the evaluation process, the emissions data are screened for adequate definition of process and fuel parameters that may affect emissions as well as validity and accuracy of sampling and analysis method. The screening mechanism is devised to reject emissions data that would be of little or no use. Acceptance of emissions data in this screening step only indicates the possibility for further analysis, and in no way suggests that these data are valid or reliable. As such, the data screening criteria are often expressed in terms of minimum requirements. These screening criteria are depicted in Figure A-1 and discussed in detail below.

The first criterion that will be applied is that only source test data will be accepted. A significant portion of the data base, and especially those contained in the National Emissions Data System (NEDS), were developed by the use of standard emission factors* and not derived from actual test data. The inclusion of these estimated emissions data in the data base would lead to the obviously biased conclusion that the actual emissions were the same as those predicted by the standard emission factors.

The second criterion that will be applied is an adequate description of the source. In order to further analyze the emissions data, there must be sufficient information to designate the combustion source according to the

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*Mostly by the use of emission factors published in the EPA Publication AP-42 "Compilation of Air Pollutant Emissions Factors."

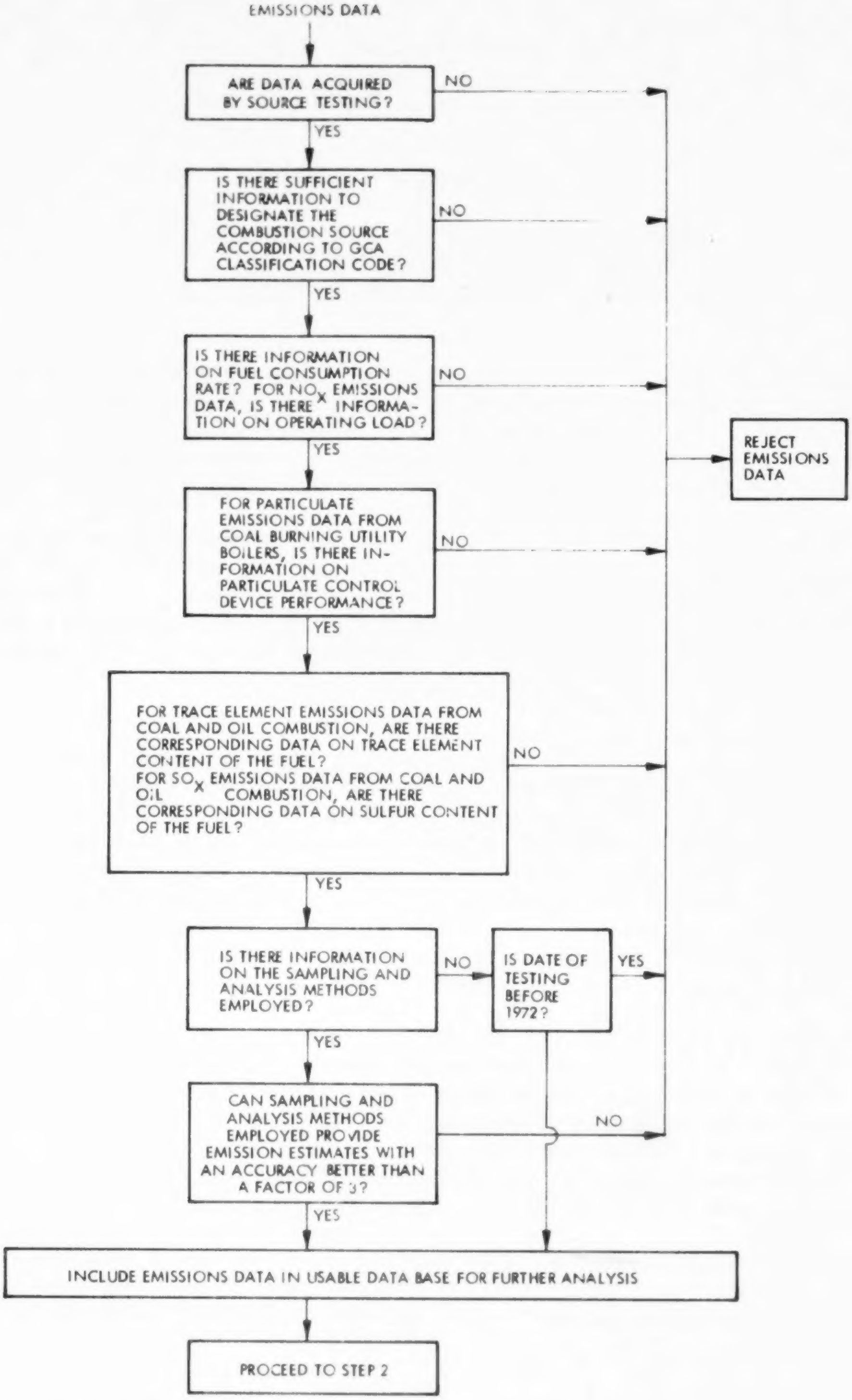
EMISSIONS DATA
ARE DATA ACQUIRED BY SOURCE TESTING?
NO
YES
IS THERE SUFFICIENT INFORMATION TO DESIGNATE THE COMBUSTION SOURCE ACCORDING TO GCA CLASSIFICATION CODE?
NO
YES
IS THERE INFORMATION ON FUEL CONSUMPTION RATE? FOR NOx EMISSIONS DATA, IS THERE INFORMATION ON OPERATING LOAD?
NO
YES
REJECT EMISSIONS DATA
FOR PARTICULATE EMISSIONS DATA FROM COAL BURNING UTILITY BOILERS, IS THERE INFORMATION ON PARTICULATE CONTROL DEVICE PERFORMANCE?
NO
YES
FOR TRACE ELEMENT EMISSIONS DATA FROM COAL AND OIL COMBUSTION, ARE THERE CORRESPONDING DATA ON TRACE ELEMENT CONTENT OF THE FUEL? FOR SOx EMISSIONS DATA FROM COAL AND OIL COMBUSTION, ARE THERE CORRESPONDING DATA ON SULFUR CONTENT OF THE FUEL?
NO
YES
IS THERE INFORMATION ON THE SAMPLING AND ANALYSIS METHODS EMPLOYED?
NO
IS DATE OF TESTING BEFORE 1972?
YES
YES
CAN SAMPLING AND ANALYSIS METHODS EMPLOYED PROVIDE EMISSION ESTIMATES WITH AN ACCURACY BETTER THAN A FACTOR OF 3?
NO
YES
INCLUDE EMISSIONS DATA IN USABLE DATA BASE FOR FURTHER ANALYSIS
PROCEED TO STEP 2

Figure A-1. Step 1 Screening Mechanism for Emissions Data appropriate GCA classification code. As a minimum, the information provided should include: the function of the combustion source (electricity generation, industrial, commercial/institutional, or residential), the type of combustion (external combustion or internal combustion), the type of fuel used (coal, oil, gas or refuse), and in the case of coal combustion, the type of furnace (pulverized dry bottom, pulverized wet bottom, cyclone, or stoker). For emissions data that are judged to be valuable* and otherwise acceptable, efforts will be made to acquire the needed source description information directly from the investigator or the plant operator.

The third criterion for acceptance of emissions data for further analysis is an adequate definition of the combustion system operating mode. For example, operating load has a large effect on NO_x emissions from combustion systems. It is therefore important to have an adequate definition of the test conditions that may affect emissions. As a minimum, there must be information on the fuel consumption rate for the emissions data to be accepted. The fuel consumption rate is necessary for the calculation of emission factors. For NO_x emissions data, field and tests results that do not include information on operating load will be considered unacceptable because they cannot be used to estimate emissions from a typical combustion system nor could they be used to estimate emissions at any specific load. For other types of emission data, the operating load information will be considered as a useful parameter for data correlation but not an absolute requirement for data acceptance.

The fourth criterion for acceptance of emissions data for further analysis is an adequate definition of the pollution control device performance. Control device performance will affect not only total emissions but will influence, for example, the particle size distribution and composition of flue gas emissions. The application of design efficiencies must be approached with caution in estimating uncontrolled emissions. If a design efficiency of 99 percent is used and if the control device operating efficiency is only 90 percent, the calculated uncontrolled emissions would be 10 times larger than the actual case. Since most coal burning utility boilers are equipped with particulate control devices, particulate emissions data from the coal burning utility sector will not be considered acceptable unless accompanied by the particulate control device performance data. The application of particulate control devices are lower for the industrial, commercial/institutional and residential sectors, and also much lower for the oil burning utility sector and nonexistent for the gas burning utility sector. For these combustion source types, emissions data will be accepted as uncontrolled emissions data, unless there is information implying the contrary. As noted in the foregoing discussions, acceptance of emissions data at this screening step does not suggest that the data are necessarily valid or reliable. In the second step of the data evaluation process, methods for rejecting outlying data points will be defined. Controlled emissions data that have been mistakenly assumed to be uncontrolled emissions data due to lack of information will be identified as outlying data points and be rejected in this second step.

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*In this context, emissions data for trace elements, POM, PCB, and organics are considered to be more valuable because of the paucity of data.

The fifth criterion that will be employed in judging the usefulness of the emissions data is the availability of fuel analysis data. This is especially true for emissions of trace elements, and SO_x. The trace element content of coal can vary by one to two orders of magnitude and emissions are closely related to the trace element content of the coal. No trace elements are present in appreciable amounts in gaseous hydrocarbons; however, Ni, V and Na are present in appreciable amounts in some fuel oil. In order to estimate trace element emission levels from all sources within a given category, the fraction of each trace element exiting the system in each effluent stream must be estimated. Thus, trace element emissions data from coal and oil combustion that are not accompanied by analysis data on the trace element content of the fuel will not be accepted. Similarly, SO_x emissions are directly related to the sulfur content of the fuel. SO_x emissions data from coal and oil combustion that do not include information on the sulfur content of the fuel will therefore not be accepted.

The last criterion that will be applied is an evaluation of the accuracy of the sampling and analysis methods employed. In order to determine emissions from a given site to within a factor of 3, both the sampling and analysis procedures employed must be capable of providing an accuracy which is better than a factor of 3. The list of methods available for the sampling and analysis of general stream types and chemical classes and species is very extensive, and has been described in detail in two recent TRW reports (References A-1 and A-2). In general, most of the sampling and analysis procedures recommended in these two references are adaptations of standard EPA, ASTM, API methods, and have an accuracy and/or precision of ± 10 to 20 percent or better. Emissions data obtained by these recommended methods or techniques will be considered acceptable. Emissions data obtained by methods or techniques not listed in these two references will be subjected to careful review, and rejected if it is determined that the sampling or analysis method employed would not be able to provide emission estimates within an accuracy factor of 3 or better. Special emphasis will be placed on the review of sampling and analysis methods used for obtaining PCB, POM, particulate sulfate, and trace elements emissions data. In cases where information on the sampling and analysis methods employed is unavailable, the date of testing will be used as the criterion for inclusion or rejection of the emissions data in the usable data base. Emissions data obtained before 1972 will be generally considered as unacceptable due to the probable use of unreliable sampling or analysis procedures. The 1972 cut-off date is selected on the basis that the EPA Method 5, which has been more or less recognized nationally as the standard method for sampling particulates, was introduced in late 1971. Furthermore, most of the more sophisticated sampling and analysis techniques for obtaining emissions data, and especially those for measuring pollutants for which data are lacking (such as trace elements and particulate sulfate), were not introduced and is used before 1972.

STEP 2

In the second step of the data evaluation process, emissions data which have been identified as usable in the screening step will be subjected to further engineering and statistical analysis to determine the internal consistency of the test results and the variability in emissions factors.

Emissions data included in the usable data base will first be categorized according to the 5 column GCA combustion system classification code and the unit operation from which the pollutants are emitted. For NO_x, the emissions data will be further categorized according to the method of NO_x control; no control, staged firing, low excess air, reduced load, or flue gas recirculation. Emissions factors for individual sites, normally expressed in the form of lb/MM Btu or lb/ton, will then be calculated for each pollutant/unit operating pair. In the case of trace element stack emissions from coal and oil combustion, these emission factors will be calculated in the form of the fraction of each trace element emitted to the atmosphere.

The emission factors calculated for each pollutant/unit operation pair will be evaluated in terms of consistency of test results among sites. All the data points that lie outside the upper and lower limits of reasonable data will be subjected to detailed scrutiny, and discarded unless there is additional information to reclassify the data into the correct category. The decision whether an outlier is a reasonable result or whether it may be discarded as being an improbable member of the group will be based on the method of Dixon. The method of Dixon is a statistical technique applicable to the rejection of a single outlying point from a small group of data, and is described in detail in Attachment A.

The variability of the emission factors will next be calculated. The variability is defined as

$$V = \frac{t\ s(\overline{x})}{(\overline{x})} \tag{1}$$

where $\overline{x}$ is the estimated mean value of the emission factor, $s(\overline{x})$ is the estimated standard deviation of the mean, and t is a multiple of the estimated standard deviation of the mean value $s(\overline{x})$. The value of t depends on the degree of freedom and the confidence level of the interval containing the true mean μ, and is given in standard statistics texts. For the present program, that t values at 95 percent confidence level will be used in calculating the variability of emission factors.

The main thrusts in this second step are: (1) to determine the emission factors for each pollutant/unit operation pair and for each combustion source category; (2) to discard outlying data points using the method of Dixon; and (3) to calculate the percent variability of the emission factors. The values calculated in this step will be used in Step 3.

STEP 3

The final step in the data evaluation process involves a method developed by the Monsanto Research Corporation (MRC) for the evaluation of data adequacy. This quantitative method will indicate where additional emissions data are needed. The method is based on both the potential environmental risks associated with the emission of each pollutant and the quality of the existing emissions data.

The potential environmental risks associated with pollutant emissions are determined by the use of source severity factors S. For emissions to the atmosphere, the source severity S is defined as the ratio of the calculated maximum ground level concentrations of the pollutant species to the level at which a potential environmental hazard exists. The simple Gaussian Plume equation for ground level receptors at the plume centerline is the disperion model used for determining the ground level concentration. The potential environmental hazard level is taken to be the Threshold Limit Value (TLV) divided by 300 for noncriteria pollutants and the ambient air quality standard for the criteria pollutants. The mean source severity S for noncriteria pollutants is calculated as follows:

$$S = \frac{5.5\ Q}{(TLV)h^2} \tag{2}$$

where Q = emission rate, g/s

TLV = threshold limit value, g/m^3

h = stack height, m

For the five criteria pollutants, the equations for calculating mean source severity S is given in the following table:

Pollutant	Severity equation	
Particulate	$S = 70Qh^{-2}$	(3)
SO_x	$S = 50Qh^{-2}$	(4)
NO_x	$S = 315Qh^{-2.1}$	(5)
Hydrocarbons	$S = 162.5Qh^{-2}$	(6)
CO	$S = 0.78Qh^{-2}$	(7)

The emission rate is calculated by the following equation:

$$Q = \frac{TC}{TNP}\ (EF)\ (GPP)\ (YPS) \tag{8}$$

where TC = total fuel consumption, tons/year

TNP = total number of plants/sites

EF = emission factor, lb/ton

GPP = 453.6 g/lb

YPS = 3.1688×10^{-8} yr/s

For discharges to the water, the source severity factor S is calculated as follows:

$$S = \frac{V_D\ C_D + S_G\ f_1 f_2}{V_R D} \tag{9}$$

where V_D = discharge flow rate, m^3/s

C_D = discharge concentration, g/m^3

S_G = leachable solid waste generation, g/sec

f_1 = fraction of the solid waste to water

f_2 = fraction of the material in the solid waste

V_R = river flow rate, m^3/s

D = drinking water standard, g/m^3

The mean source severity factor S for each pollutant/unit operation pair will be used in the evaluation of data adequacy. The method for evaluating data adequacy is outlined below.

Case 1: When Emissions Data Are Available and Usable

1. Determine the mean emission factor $\bar{x}$ and the variability of the emission factor $ts(\bar{x})/\bar{x}$ for each pollutant/unit operation pair. (This will be done in Step 2 of the data evaluation process.)

2. Determine the mean severity factor S for each pollutant/unit operation pair by using the mean emission factor $\bar{x}$.

3. If the variability in emission factor < 70 percent, there is no need for additional data.

4. If the variability in emission factor > 70 percent and $S > 0.05$, the current data base is judged to be inadequate and there is need for additional data.

5. If the variability in emission factor > 70 percent and $S \leq 0.1$, determine the severity factor S_u by using the emission factor $\bar{x}_u$:

   $$\bar{x}_u = \bar{x} + ts(\bar{x})$$

   S_u is the upper bound for the severity factor S. The current data base is judged to be adequate if $S_u \leq 0.05$ and inadequate if $S_u > 0.05$.

Case 2: When Emissions Data Are Not Available

1. Determine, if possible, from fuel analysis, mass balance and physico-chemical considerations the upper bound $\bar{x}_u$ of the emission factor $\bar{x}$. For trace element stack emissions, for example, $\bar{x}_u$ can be determined by assuming that all the trace elements present in the fuel are emitted through the stack.

2. Determine the upper bound S_u of the severity factor S for each pollutant/unit operation pair by using the emission factor $\bar{x}_u$.

3. The current data base is judged to be adequate if $S_u \leq 0.05$ and inadequate if $S_u > 0.05$.

As discussed in a recent Monsanto report (Reference A-3), an allowable uncertainty in emission factor of ± 70 percent (factor of 3) would lead to an uncertainty of less than 10 in S_{calc}, which has been defined as the acceptable uncertainty factor for S.

As a result of the application of the above data evaluation criteria, pollutant/unit operation pairs that have been inadequately characterized will be identified to permit the planning of field tests for acquisition of additional emissions data.

ATTACHMENT A

METHOD OF DIXON FOR DISCARDING OUTLYING DATA*

The method of Dixon provides a test for extreme values using range. If the observations in the sample are ranked, the individual values can be identified x_1, x_2, x_3, . . ., x_{n-1}, x_n. It is immaterial whether the ranking proceeds from high values to low or from low values to high. The Dixon extreme-value test gives the maximum ratio of differences between extreme-ranking observations to be expected at various probability levels and for different sample sizes. Table A-1 gives the test ratios and maximum expected values. For samples less than about eight observations, the ratio of the difference between the extreme and the next-to-extreme value to the total range is compared with the tabulated values for the same sample size. If the observed ratio exceeds the tabulated maximum expected ratio, the extreme value may be rejected with the risk of error set by the probability level. For samples between about 9 and 14, test the ratio of the difference between the first and third ranking observations to the difference between the first and next to last. For samples of 15 or more, use the ratio of the difference between the first and third ranking observations to the difference between the first-and the second-from last observation.

In the evaluation of the emissions data, the 0.05 probability level will be used as the basis for discarding outlying data.

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*Volk, W. Applied Statistics for Engineers. New York McGraw-Hill, Inc. 2nd ed. p. 387-388. 1969.

TABLE A-1. MAXIMUM RATIO OF EXTREME RANKING OBSERVATIONS

Recommended for sample size	Rank difference ratio	Sample size, n	Maximum ratio		
			Probability level		
			0.10	0.05	0.01
$n < 8$	$\frac{x_2 - x_1}{x_n - x_1}$	3	0.886	0.941	0.988
		4	0.679	0.765	0.889
		5	0.557	0.642	0.780
		6	0.482	0.560	0.698
		7	0.434	0.507	0.637
$8 < n < 15$	$\frac{x_3 - x_1}{x_{n-1} - x_1}$	8	0.650	0.710	0.829
		9	0.594	0.657	0.776
		10	0.551	0.612	0.726
		11	0.517	0.576	0.679
		12	0.490	0.546	0.642
		13	0.467	0.521	0.615
		14	0.448	0.501	0.593
$n \overset{-}{>} 15$	$\frac{x_3 - x_1}{x_{n-2} - x_1}$	15	0.472	0.525	0.616
		16	0.454	0.507	0.595
		17	0.438	0.490	0.577
		18	0.424	0.475	0.561
		19	0.412	0.462	0.547
		20	0.401	0.450	0.535

REFERENCES

A-1. Hamersma, J.W., S.C. Reynolds, and R.F. Maddalone. IERL-RTP Procedures Manual: Level 1 Environmental Assessment. EPA-600/2-76-160a. p. 131. June 1976.

A-2. Maddalone, R.F. and S.C. Quinlivan. Technical Manual for Inorganic Sampling and Analysis. Report prepared by TRW, Inc. for the U.S. Environmental Protection Agency. EPA-600/2-77-024. January 1977.

A-3. Eimutis, E.C. Source Assessment: Prioritization of Stationary Air Pollution Sources--Model Description. Report prepared by Monsanto Research Corporation for the U.S. Environmental Protection Agency. EPA-600/2-76-032a. February 1976.

APPENDIX B

APPENDIX B

PLUME RISES FOR INTERNAL COMBUSTION SOURCES

The source severity factor, as used in the current study, is the ratio of the calculated maximum ground level concentration of the pollutant species for an isolated typical source to the level at which a potential environmental hazard exists (Reference B-1). In general, the potential environmental hazard level is taken to be the Threshold Limit Value (TLV) divided by 300 for non-criteria pollutants and the primary ambient air quality standard for the criteria pollutants.

In the calculation of maximum ground level concentrations as proposed in Reference B-1, physical stack heights are always used and plume rises have not been taken into account. This appears to present a special problem in the calculation of severity factors for internal combustion sources, which are typically characterized by short stacks (6 m), and high exhaust gas temperatures and velocities. The effective emission height for internal combustion sources could be 2 to 30 times the physical stack height. The overall result is that ambient concentrations and source severity factors calculated using physical stack heights could lead to values overestimated by a factor of 4 to 900.

To correct for this deficiency, it was proposed to use Holland's formula to estimate plume rise from internal combustion sources (Reference B-2):

$$\Delta h = \frac{V_s d}{U}\left(1.5 + 2.68 \times 10^{-3} p \frac{T_s - T_a}{T_s} d\right)$$

where Δh = plume rise, m

V_s = stack gas exit velocity, m/sec

d = inside diameter of study, m

U = wind speed at source height, m/sec

p = atmospheric pressure, mb

T_s = stack gas temperature, °K
T_a = air temperature, °K.

Estimated plume rises for internal combustion sources, using field data acquired during this program and Holland's formula, are given in Table B-1. With an average physical stack height of 6.1 m (20 ft), the average effective emission height should, therefore, be 159 m for electricity generation gas turbines and 16.9 m for electricity generation reciprocating engines.

Average plume rises for industrial gas turbines could be estimated from the field data for electricity generation gas turbines. The assumptions used in the calculation included:

1) exhaust gases from industrial and electricity generation gas turbines have similar temperatures and exit velocities;

2) exhaust stacks for industrial and electricity generation gas turbines are sized such that the cross sectional areas of stacks are proportional to their rated capacities.

Utilizing this approach, the average plume rise and the average effective emission height for industrial gas turbines were estimated to be 17.9 m and 24.0 m, respectively.

For reciprocating engines, the average sizes for the electricity generation and industrial sectors are similar. The average effective emission height for industrial reciprocating engines could, therefore, be assumed to be 16.9 m, the same as that estimated for electricity generation reciprocating engines.

TABLE B-1. ESTIMATED PLUME RISES FOR INTERNAL COMBUSTION SOURCES

Combustion Source Type	Site No.	Stack Diameter (m)	Exhaust Gas Temperature (°K)	Exhaust Gas Velocity (m/sec)	Plume Rise (m)
Gas Fueled Gas Turbine	#110	2.74	732	37.8	136
Distillate Oil Fueled Gas Turbine	#111	2.74	753	37.8	138
	#112	ND*	718	ND*	
	#306	4.10	527	24.7	143
	#307	4.10	649	27.9	191
	#308	3.61	689	27.8	158
Average Plume Rise for Gas Turbine					153
Diesel Engine	#309	0.86	640	23.0	12.2
	#310	0.84	631	21.5	10.8
	#311	0.84	612	34.3	17.0
	#312	0.71	537	20.6	7.7
	#313	0.71	552	17.0	6.4
Average Plume Rise for Reciprocating Engines					10.8

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*ND - Not Determined.

REFERENCES

B-1. Eimutis, E.C. Source Assessment: Prioritization of Stationary Air Pollution Sources--Model Description. Report prepared by Monsanto Research Corporation for the U.S. Environmental Protection Agency. EPA-600/2-76-032a. February 1976.

B-2. Turner, D.B. Workbook of Atmospheric Dispersion Estimates. U.S. Environmental Protection Agency, Publication No. AP-42. 1970.

APPENDIX C

APPENDIX C

DATA REDUCTION PROCEDURE

Stack emissions data reported from field measurements or laboratory analyses are often expressed in terms of volume concentration (ppmv) or mass concentration (mg/m^3, µg/m^3). To convert these emissions data to the emission factor form, the following data reduction procedure, adopted from Reference B-1, is used.

The number of gm moles of flue gas per gm of fuel can be computed using the fuel composition analysis and effluent O_2 concentration:

$$n_{FG} = \frac{4.762\ (n_C + n_S) + .9405\ n_H - 3.762\ n_{O_2}}{1 - 4.762\ (O_2/100)} = \frac{F}{1 - 4.762\ (O_2/100)}$$

where: n_{FG} = gm moles of dry effluent/gm of fuel under actual operating conditions.

n_j = gm moles of element j in fuel per gm of fuel.

O_2 = volumetric O_2 concentration in percent.

F = gm moles of dry effluent/gm of fuel under stoichiometric combustion.

The average values of F for natural gas and various liquid fuels are given in Table B-1. The value of F for coal must be computed on an individual basis because of the variation in the elemental composition of different coals.

For emission species measured on a volumetric concentration basis (ppmv), the emission factor expressed as ng/J can be computed using the following equation:

$$\begin{Bmatrix}\text{Emission}\\\text{Factor}\end{Bmatrix}(\text{ng/J}) = \frac{\begin{Bmatrix}\text{Volumetric}\\\text{Concentration}\end{Bmatrix}_s (\text{ppmv}) \times F \times M_s}{\begin{Bmatrix}\text{Fuel}\\\text{Heating Value}\end{Bmatrix} (\text{kJ/kg fuel})} \text{ X } \frac{1000}{1 - 4.762\ (O_2/100)}$$

where s = subject emission species

M_s = molecular weight of species s

For emission species measured on a mass concentration basis (mg/m^3 or $\mu g/m^3$) at 20°C, the emission factor expressed as ng/J, can be computed using the following equation:

$$\begin{Bmatrix}\text{Emission}\\\text{Factor}\end{Bmatrix}(\text{ng/J}) = \frac{\begin{Bmatrix}\text{Mass}\\\text{Concentration}\end{Bmatrix}_s (\mu g/m^3) \times F \times 24.04}{\begin{Bmatrix}\text{Fuel}\\\text{Heating Value}\end{Bmatrix} (\text{kJ/kg fuel})} \text{ X } \frac{1}{1 - 4.762\ (O_2/100)}$$

The higher heating values of natural gas and various liquid fuels are also given in Table B-1.

It should be noted that the data reduction procedure described here significantly minimizes errors introduced in data reduction by eliminating terms which are subject to large measurement errors, such as stack velocity and temperature measurements. The only stack parameter needed in data reduction is the volumetric O_2 concentration, which usually can be determined by gas chromatography with great accuracy.

Example Calculation --

The NO_x emission from a gas fueled gas turbine is reported to be 200 ppmv at an O_2 effluent concentration of 15%. Calculate the emission factor for NO_x (as NO_2) in kg/GJ.

Emission factor for NO_x (as NO_2)

$$= \frac{200 \times 0.51215 \times 46.0}{53310} \times \frac{1000}{1 - 4.762 \times 0.15} \text{ ng/J}$$

$$= 309 \text{ ng/J}$$

TABLE C-1. ELEMENTAL COMPOSITION AND HIGHER HEATING VALUE OF FUELS[*]

Fuel	Natural Gas	No. 2 Distillate Oil	Kerosene	Resid Oil
n_C	0.06221	0.06994	0.06994	0.07160
n_S	0	0.00006	0	0.00031
n_H	0.23116	0.13889	0.15873	0.10913
n_O	0.00040	0.001125	0	0.00125
F	0.51215	0.45983	0.48234	0.44037
Heating Value	53,310 kJ/kg	45,040 kJ/kg	47,710 kJ/kg	43,760 kJ/kg

[*] The composition and heating value data are obtained from Reference C-2.

REFERENCES

C-1. Coppersmith, F. M., R. F. Jastrzebski, D. V. Giovanni and S. Hersh. Con Edison's Gas Turbine Test Program: A Comprehensive Evaluation of Stationary Gas Turbine Emission Levels. Paper presented at the 67th Annual Meeting of the Air Pollution Control Association, Denver, Colorado, June 9-13, 1974.

C-2. Steam/Its Generation and Use. Revised 38th Edition. The Babcock and Wilcox Company, New York, New York. 1975.

APPENDIX D

TABLE D-1. SASS TRAIN DISTRIBUTION FOR SPECIFIC INORGANICS, GAS-FUELED GAS TURBINE (SITE 110)

Species	Particulate*	XAD-2 (mg)	Impingers		Total Catch (mg)	Found Mass Emissions (mg/DSCM)
			Composite† (mg)	APS‡ (mg)		
Hg	-	.29	<.00032	-	.29	.0091
As	-	**	<.044	-	<.044	<.0014
Sb	-	<.037	<.015	-	<.052	<.0016
SO_4	-	120	-	-	120	3.8
F	-	*	*	-	-	-
Cl	-	23	5.9	-	29	.89

[*] There was no particulate sample for Site 110.

[†] Composite of HNO_3 module wash, condensate, and the H_2O_2 impinger.

[‡] The second impinger containing ammonium persulfate (APS) and silver nitrate and the third impinger containing APS.

[**] Blank values equal to or slightly higher than sample concentrations.

SITE 110: VOLUME SAMPLED = 32.0 DSCM

TABLE D-2. SSMS DATA FOR GAS-FUELED GAS TURBINE

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
RU	< 0.030	< 0.0060	< 0.036	< 0.0011
MO	< 0.084	0.011	0.011 TO 0.084	0.0003 TO 0.0026
NB	0.0010	< 0.0055	0.0010 TO 0.0055	< 0.0001 TO 0.0002
ZR	< 0.027	0.0006	0.0006 TO 0.027	< 0.0001 TO 0.0008
Y	< 0.027	< 0.0052	< 0.032	< 0.0010
SR	< 0.16	0.0053	0.0053 TO 0.16	0.0002 TO 0.0049
RB	0.011	0.0009	0.012	0.0004
BR	< 0.17	0.041	0.041 TO 0.17	0.0013 TO 0.0054
SE	< 0.034	< 0.0095	< 0.044	< 0.0014
AS	< 0.038	< 0.0044	< 0.043	< 0.0013
GE	< 0.022	< 0.0043	< 0.026	< 0.0008
GA	< 0.021	< 0.0041	< 0.025	< 0.0008
ZN	< 2.4	0.18	0.18 TO 2.4	0.0055 TO 0.075
CU	2.2	< 0.32	2.2	0.069
NI	< 2.5	0.15	0.15 TO 2.5	0.0046 TO 0.078
CO	< 0.027	0.0022	0.0022 TO 0.027	< 0.0001 TO 0.0009
FE	< 4.9	0.57	0.57 TO 4.9	0.018 TO 0.15
MN	< 0.24	0.082	0.082 TO 0.24	0.0026 TO 0.0076
CR	< 0.35	0.089	0.089 TO 0.35	0.0028 TO 0.011
V	< 0.016	0.0019	0.0019 TO 0.016	< 0.0001 TO 0.0005
TI	< 0.19	0.0061	0.0061 TO 0.19	0.0002 TO 0.0060
CA	< 7.3	0.43	0.43 TO 7.3	0.013 TO 0.23
K	< 5.0	0.50	0.50 TO 5.0	0.016 TO 0.16
S	< 18.	9.6	9.6	0.30
P	< 1.7	0.084	0.084 TO 1.7	0.0026 TO 0.053
SI	< 3.7	0.28	0.28 TO 3.7	0.0089 TO 0.11
AL	< 1.4	< 0.12	< 1.5	< 0.048
MG	< 6.0	0.28	0.28 TO 6.0	0.0088 TO 0.19
NA	< 2.8	< 2.6	< 5.3	< 0.17
B	< 0.011	0.11	0.11	0.0035
BE	< 0.0027	< 0.0001	< 0.0001 TO 0.0027	< 0.0001 TO 0.0001
LI	< 0.0071	< 0.0006	< 0.0077	< 0.0002

- Continued -

SITE 110:   VOLUME SAMPLED = 32.0 DSCM

TABLE D-2 (Continued)

ELEMENT	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)
U	< 0.071	< 0.014	< 0.085	< 0.0027
TH	< 0.070	< 0.014	< 0.083	< 0.0026
BI	< 0.063	< 0.012	< 0.075	< 0.0023
PB	< 0.46	0.051	0.051 TO 0.46	0.0016 TO 0.014
TL	< 0.061	< 0.012	< 0.073	< 0.0023
AU	< 0.059	< 0.012	< 0.071	< 0.0022
IR	< 0.058	< 0.011	< 0.069	< 0.0022
OS	< 0.057	< 0.011	< 0.068	< 0.0021
RE	< 0.056	< 0.011	< 0.067	< 0.0021
W	< 0.055	< 0.011	< 0.066	< 0.0021
HF	< 0.054	< 0.011	< 0.064	< 0.0020
LU	< 0.052	< 0.0100	< 0.063	< 0.0020
YB	< 0.052	< 0.0100	< 0.062	< 0.0019
TM	< 0.051	< 0.0099	< 0.061	< 0.0019
ER	< 0.050	< 0.0049	< 0.060	< 0.0019
HO	< 0.049	< 0.0097	< 0.059	< 0.0018
DY	< 0.049	< 0.0096	< 0.058	< 0.0018
TB	< 0.048	< 0.0094	< 0.057	< 0.0018
GD	< 0.047	< 0.0093	< 0.056	< 0.0018
EU	< 0.046	< 0.0090	< 0.055	< 0.0017
SM	< 0.045	< 0.0089	< 0.054	< 0.0017
ND	< 0.043	< 0.0085	< 0.052	< 0.0016
PR	< 0.042	< 0.0083	< 0.051	< 0.0016
CE	0.0073	0.0009	0.0082	0.0003
LA	< 0.042	0.0014	0.0014 TO 0.042	< 0.0001 TO 0.0013
BA	< 2.6	0.030	0.030 TO 2.6	0.0009 TO 0.083
CS	0.0006	< 0.0078	0.0006 TO 0.0078	< 0.0001 TO 0.0002
I	< 0.038	< 0.0075	< 0.046	< 0.0014
TE	< 0.038	< 0.0075	< 0.046	< 0.0014
SB	< 0.067	0.0042	0.0042 TO 0.067	0.0001 TO 0.0021
SN	< 0.13	0.014	0.014 TO 0.13	0.0004 TO 0.0042
CD	< 0.012	0.015	0.015	0.0005
PD	< 0.032	< 0.0063	< 0.038	< 0.0012
RH	< 0.031	< 0.0061	< 0.037	< 0.0012

TABLE D-3. SASS TRAIN DISTRIBUTION FOR SPECIFIC INORGANICS, DISTILLATE OIL-FUELED GAS TURBINE (SITES 111, 112)

Site	Species	Particulate (mg)	XAD-2 (mg)	Impingers		Total Catch (mg)	Found Mass Emissions (mg/DSCM)	Fuel Feed (μg/g)	Calculated Mass Emissions (mg/m^3)
				Composite[†] (mg)	APS[‡] (mg)				
111	Hg	<0.0003	0.0031	0.0025	0.001	0.0057	0.00018	.04	0.00026
	As	<0.019	<0.11	<0.023	0.018	0.018-0.17	0.00059-0.0056	<.015	<0.000099
	Sb	<0.023	<0.037	<0.076	0.0064	0.0064-0.14	0.00021-0.0046	<.025	<0.0016
	SO_4	**	60.	-	-	60.	2.0*	2049	14.
	F	**	**	0.31	-	0.31	0.010	20	0.50
	Cl	1.0	150.	<0.76	-	150.	4.9	100	0.66
	NO_3	0.87	-	-	-	0.87	0.029	-	-
112	Hg	0.0002	0.042	0.0019	0.00085	0.045	0.0014	.48	0.0069
	As	**	0.060	<0.031	<0.018	0.06-0.11	0.0018-0.0033	<.015	<0.00022
	Sb	<0.00098	0.40	0.010	<0.006	0.41	0.013	<.25	<0.0036
	SO_4	7.6	90.	-	-	98.	3.0*	2199	32.
	F	**	0.75	0.84	-	1.6	0.049	20	0.29
	Cl	1.1	45.	36.	<0.62	82.	2.5	50	0.72
	NO_3	0.59	-	-	-	0.59	0.018	-	-

*SO_4 values do not represent total sulfur in the SASS train.

[†] Composite of HNO_3 module wash, condensate, and the H_2O_2 impinger.

[‡] The second impinger containing ammonium persulfate (APS) and silver nitrate and the third impinger containing APS.

**Blank values equal to or slightly higher than sample concentrations.

TABLE D-4. SASS TRAIN DISTRIBUTION FOR SPECIFIC INORGANICS, DISTILLATE OIL-FUELED GAS TURBINE (SITES 306, 307, 308)

Site	Species	Particulate (mg)	XAD-2 (mg)	Impingers		Total Catch (mg)	Found Mass Emissions (mg/DSCM)	Fuel Feed (μg/g)	Calculated Mass Emissions (mg/DSCM)
				Composite† (mg)	APS‡ (mg)				
306	Hg	<.00002*	<.0056*	<.00092	<.02	<.027	<.00074	.024	.00062
	As	<.00013	<.0013	<.00092	<.00098	<.0033	<.00009	.097	.0025
	Sb	<.00013	.058	<.00092	<.00098	.060	.0017	.0097	.0025
	SO_4	1.29	31.7	-	-	33.	0.91**	1200.	29.8
307	Hg	<.00001*	<.0054*	<.024	<.021	<.050	<.0016	.007	.00016
	As	<.00001	<.0012	<.0012	<.0010	<.0034	<.00011	.099	.0025
	Sb	.0054	.055	<.0012	<.0010	.063	.0019	.099	.0025
	SO_4	2.3	128.	-	-	130.	4.2**	700.	92.1
308	Hg	<.00003*	<.00012	<.0023	<.022	<.025	<.00083	.003	.00016
	As	.0012	<.0024	<.0011	<.0011	.0012	.0004	.099	.0056
	Sb	<.0002	<.0024	<.0011	<.0011	<.0048	<.00016	.69	.039
	SO_4	2.05	9.6	-	-	12.	0.40**	690.	38.8

*Blank values equal to or higher than samples.

†Composite of HNO_3 module wash, condensate, and the H_2O_2 impinger.

‡The second impinger containing ammonium persulfate (APS) and silver nitrate and the third impinger containing APS.

**SO_4 values do not represent total sulfur in the SASS train.

SITE 111: VOLUME SAMPLED = 30.4 DSCM

TABLE D-5. SSMS DATA FOR DISTILLATE OIL-FUELED GAS TURBINES (SITE 111)

ELEMENT	PROBE SOLIDS (MG)	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0005	< 0.011	< 0.071	< 0.0087	< 0.092	< 0.0030	< 0.48	< 0.0031
TH	< 0.0005	< 0.011	< 0.070	< 0.0085	< 0.089	< 0.0029	< 0.46	< 0.0030
BI	< 0.0004	< 0.0098	< 0.063	< 0.0076	< 0.081	< 0.0026	< 0.42	< 0.0027
PB	0.017	0.069	< 0.77	0.18	0.26 TO 0.77	0.0087 TO 0.025	1.5	0.0085
TL	< 0.0004	< 0.0096	< 0.061	< 0.0074	< 0.079	< 0.0026	< 0.41	< 0.0027
AU	< 0.0004	0.041	< 0.059	< 0.0072	0.041	0.0013	< 0.39	< 0.0026
IR	< 0.0004	< 0.0090	< 0.058	< 0.0070	< 0.074	< 0.0024	< 0.38	< 0.0025
OS	< 0.0004	< 0.0089	< 0.057	< 0.0074	< 0.074	< 0.0024	< 0.38	< 0.0025
RE	< 0.0004	< 0.0088	< 0.056	< 0.0068	< 0.072	< 0.0024	< 0.37	< 0.0024
W	< 0.0004	< 0.0086	< 0.055	< 0.0067	< 0.071	< 0.0023	< 0.37	< 0.0024
HF	< 0.0004	< 0.0084	< 0.054	< 0.0078	< 0.070	< 0.0023	< 0.36	< 0.0023
LU	< 0.0003	< 0.0082	< 0.052	< 0.0064	< 0.067	< 0.0022	< 0.35	< 0.0023
YB	< 0.0003	< 0.0081	< 0.052	< 0.0063	< 0.067	< 0.0022	< 0.35	< 0.0023
TM	< 0.0003	< 0.0079	< 0.051	< 0.0061	< 0.065	< 0.0021	< 0.34	< 0.0022
ER	< 0.0003	< 0.0079	< 0.050	< 0.0061	< 0.064	< 0.0021	< 0.33	< 0.0022
HO	< 0.0003	< 0.0078	< 0.049	< 0.0060	< 0.064	< 0.0021	< 0.33	< 0.0022
DY	< 0.0003	< 0.0076	< 0.049	< 0.0059	< 0.063	< 0.0021	< 0.33	< 0.0021
TB	< 0.0003	< 0.0075	< 0.048	< 0.0058	< 0.061	< 0.0020	< 0.32	< 0.0021
GD	< 0.0003	< 0.0074	< 0.047	< 0.0057	< 0.061	< 0.0020	< 0.31	< 0.0021
EU	< 0.0003	< 0.0071	< 0.046	< 0.0055	< 0.059	< 0.0019	< 0.30	< 0.0020
SM	< 0.0003	< 0.0071	< 0.045	< 0.0055	< 0.058	< 0.0019	< 0.30	< 0.0020
ND	< 0.0003	< 0.0068	< 0.043	< 0.0059	< 0.056	< 0.0019	< 0.29	< 0.0019
PR	< 0.0003	< 0.0066	< 0.042	< 0.0051	< 0.054	< 0.0018	< 0.28	< 0.0019
CE	< 0.0001	< 0.0016	< 0.042	0.0010	0.0010 TO 0.044	< 0.0001 TO 0.0014	0.0098	< 0.0001
LA	< 0.0001	< 0.0065	< 0.042	< 0.0051	< 0.0001 TO 0.053	< 0.0001 TO 0.0018	< 0.28	< 0.0018
BA	0.0014	0.081	< 0.82	0.034	0.12 TO 0.82	0.0038 TO 0.027	1.4	0.0090
CS	< 0.0001	< 0.0001	< 0.040	< 0.0048	< 0.0001 TO 0.045	< 0.0001 TO 0.0015	< 0.27	< 0.0017
I	< 0.0002	< 0.0060	< 0.038	< 0.0046	< 0.049	< 0.0016	< 0.25	< 0.0017
TE	< 0.0003	< 0.0060	< 0.038	< 0.0046	< 0.049	< 0.0016	< 0.26	< 0.0017
SB	0.0004	< 0.0035	< 0.038	< 0.0044	0.0004 TO 0.046	< 0.0001 TO 0.0015	0.053	0.0003
SN	< 0.0006	< 0.042	< 0.11	0.15	0.15	0.0049	0.13	0.0009
CD	< 0.0001	0.0030	< 0.069	< 0.0042	0.0031 TO 0.073	< 0.0001 TO 0.0024	0.14	0.0009
PD	< 0.0002	< 0.0050	< 0.032	< 0.0039	< 0.041	< 0.0013	< 0.21	< 0.0014
RH	< 0.0002	< 0.0048	< 0.031	< 0.0037	< 0.040	< 0.0013	< 0.21	< 0.0014

- Continued -

SITE 111: VOLUME SAMPLED = 30.4 DSCM

TABLE D-5 (Continued)

ELEMENT	PROBE SOLIDS (MG)	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0002	< 0.0048	< 0.030	< 0.0044	< 0.040	< 0.0013	< 0.20	< 0.0013
MO	0.0007	0.051	0.064	0.012	0.13	0.0042	0.093	0.0006
NB	< 0.0001	< 0.0044	0.0022	0.0010	0.0033	0.0001	< 0.19	< 0.0012
ZR	< 0.0015	< 0.0088	< 0.027	< 0.0033	< 0.041	< 0.0013	< 0.18	< 0.0012
Y	0.0003	< 0.0042	< 0.027	< 0.0032	0.0003 TO 0.034	< 0.0001 TO 0.0011	< 0.18	< 0.0012
SR	0.0006	< 0.0064	< 0.14	0.012	0.012 TO 0.14	0.0004 TO 0.0047	0.33	0.0021
RB	< 0.0001	< 0.0031	0.0088	0.0007	0.0095	0.0003	0.023	0.0001
BR	0.0005	0.056	< 0.29	0.0100	0.067 TO 0.29	0.0022 TO 0.0094	< 0.55	< 0.0036
SE	0.0024	0.0083	< 0.024	0.030	0.041	0.0013	0.11	0.0007
AS	0.0009	< 0.0060	< 0.063	0.0034	0.0043 TO 0.069	0.0001 TO 0.0023	< 0.082	< 0.0005
GE	0.0005	< 0.0034	< 0.022	< 0.0026	0.0005 TO 0.028	< 0.0001 TO 0.0009	< 0.15	< 0.0009
GA	< 0.0001	< 0.0033	< 0.021	< 0.0025	< 0.027	< 0.0009	< 0.14	< 0.0009
ZN	0.0028	< 0.11	< 4.7	0.048	0.051 TO 4.8	0.0017 TO 0.16	12.	0.082
CU	0.0065	< 0.14	< 4.8	< 0.089	0.0065 TO 5.0	0.0002 TO 0.16	3.1	0.020
NI	0.056	1.5	1.3	0.041	3.0	0.097	3.2	0.021
CO	0.0023	0.044	0.024	0.0018	0.073	0.0024	0.053	0.0003
FE	0.55	51.	< 5.2	0.23	52.	1.7	18.	0.12
MN	1.3	7.7	0.26	0.27	9.5	0.31	71.	0.46
CR	0.021	0.025	0.12	0.14	0.31	0.0100	0.13	0.0009
V	0.0017	< 0.0013	< 0.019	0.0028	0.0045 TO 0.021	0.0001 TO 0.0007	0.062	0.0004
TI	0.0028	< 0.060	0.056	0.0065	0.066	0.0022	< 0.20	< 0.0013
CA	0.056	< 0.83	< 12.	2.0	2.1 TO 13.	0.069 TO 0.44	15.	0.100
K	0.026	< 0.78	< 5.0	0.23	0.26 TO 5.8	0.0086 TO 0.19	16.	0.11
S	6.5	15.	< 50.	3.3	25. TO 50.	0.83 TO 1.7	490.	3.2
P	0.0051	0.13	< 2.2	< 0.093	0.13 TO 2.3	0.0044 TO 0.075	8.8	0.058
SI	0.44	< 2.7	49.	0.23	49.	1.6	60.	0.39
AL	0.038	< 0.74	< 1.6	0.061	0.099 TO 2.3	0.0033 TO 0.076	2.7	0.018
MG	0.013	< 0.94	< 6.0	0.11	0.12 TO 6.9	0.0039 TO 0.23	< 11.	< 0.073
NA	0.0090	10.	8.4	< 1.8	19.	0.61	33.	0.21
B	0.036	< 0.075	1.6	< 0.018	1.6	0.053	3.9	0.026
BE	< 0.0001	< 0.0001	0.0001	< 0.0003	0.0002 TO 0.0003	< 0.0001 TO 0.0001	< 0.0021	< 0.0001
LI	< 0.0001	< 0.0022	< 0.066	0.0011	0.0011 TO 0.068	< 0.0001 TO 0.0022	< 0.021	< 0.0001

SITE 112: VOLUME SAMPLED = 32.6 DSCM

TABLE D-6. SSMS DATA FOR DISTILLATE OIL-FUELED GAS TURBINES (SITE 112)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0048	< 0.071	< 0.021	< 0.097	< 0.0030	< 0.65	< 0.0093
TH	< 0.0046	0.14	< 0.031	0.14	0.0044	< 0.94	< 0.013
BI	< 0.0042	< 0.063	< 0.0096	< 0.076	< 0.0023	< 0.42	< 0.0060
PB	0.083	2.0	0.034	2.1	0.064	4.3	0.062
TL	< 0.0041	< 0.061	< 0.012	< 0.077	< 0.0024	< 0.41	< 0.0059
AU	0.0008	< 0.059	< 0.016	0.0008 TO 0.075	< 0.0001 TO 0.0023	< 0.48	< 0.0069
IR	< 0.0038	< 0.080	< 0.024	< 0.11	< 0.0033	< 0.74	< 0.011
OS	< 0.0038	< 0.087	< 0.027	< 0.12	< 0.0036	< 0.81	< 0.012
RE	< 0.0037	< 0.056	< 0.017	< 0.076	< 0.0023	< 0.51	< 0.0074
W	0.0003	< 0.074	< 0.023	0.0003 TO 0.096	< 0.0001 TO 0.0030	< 0.69	< 0.0099
HF	< 0.0036	< 0.092	< 0.028	< 0.12	< 0.0038	< 0.86	< 0.012
LU	< 0.0035	< 0.052	< 0.0080	< 0.064	< 0.0020	< 0.35	< 0.0050
YB	< 0.0035	< 0.052	< 0.0096	< 0.065	< 0.0020	< 0.35	< 0.0050
TM	< 0.0034	< 0.051	< 0.0078	< 0.062	< 0.0019	< 0.34	< 0.0049
ER	< 0.0033	< 0.056	< 0.017	< 0.077	< 0.0024	< 0.52	< 0.0075
HO	< 0.0033	< 0.049	< 0.0076	< 0.060	< 0.0019	< 0.33	< 0.0047
DY	< 0.0032	< 0.049	< 0.0098	< 0.062	< 0.0019	< 0.33	< 0.0047
TB	< 0.0032	< 0.048	< 0.0073	< 0.058	< 0.0018	< 0.32	< 0.0046
GD	< 0.0031	< 0.047	< 0.0098	< 0.060	< 0.0018	< 0.31	< 0.0045
EU	< 0.0030	< 0.046	< 0.0070	< 0.056	< 0.0017	< 0.30	< 0.0044
SM	< 0.0030	< 0.056	< 0.017	< 0.076	< 0.0023	< 0.52	< 0.0075
ND	< 0.0029	< 0.070	< 0.021	< 0.094	< 0.0029	< 0.65	< 0.0093
PR	< 0.0028	< 0.042	< 0.0065	< 0.052	< 0.0016	< 0.28	< 0.0040
CE	< 0.0002	< 0.042	< 0.0064	< 0.049	< 0.0015	< 0.28	< 0.0040
LA	< 0.0001	< 0.042	< 0.0064	< 0.0001 TO 0.048	< 0.0001 TO 0.0015	< 0.28	< 0.0040
BA	< 0.023	24.	0.030	24.	0.72	14.	0.21
CS	< 0.0001	< 0.040	< 0.0061	< 0.0001 TO 0.046	< 0.0001 TO 0.0014	< 0.27	< 0.0038
I	0.0003	0.20	< 0.015	0.20	0.0061	< 0.45	< 0.0064
TE	< 0.0026	< 0.040	< 0.012	< 0.055	< 0.0017	< 0.38	< 0.0054
SB	0.016	< 0.038	< 0.0086	0.016 TO 0.046	0.0005 TO 0.0014	< 0.26	< 0.0038
SN	< 0.0089	0.11	0.021	0.13	0.0041	2.0	0.029
CD	0.011	0.072	< 0.015	0.083	0.0026	< 0.46	< 0.0067
PD	< 0.0021	< 0.040	< 0.012	< 0.054	< 0.0017	< 0.37	< 0.0054
RH	< 0.0021	< 0.031	< 0.0047	< 0.038	< 0.0012	< 0.21	< 0.0030

- Continued -

SITE 112: VOLUME SAMPLED = 32.6 DSCM

TABLE D-6 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0020	< 0.051	< 0.016	< 0.069	< 0.0021	< 0.48	< 0.0069
MO	0.0029	< 0.048	< 0.015	0.0029 TO 0.062	< 0.0001 TO 0.0019	< 0.44	< 0.0064
NB	< 0.0001	< 0.028	< 0.0043	< 0.0001 TO 0.032	< 0.0001 TO 0.0010	< 0.19	< 0.0027
ZR	< 0.0037	< 0.027	< 0.0069	< 0.038	< 0.0012	< 0.21	< 0.0030
Y	0.0002	< 0.027	< 0.0041	0.0002 TO 0.031	< 0.0001 TO 0.0009	< 0.18	< 0.0026
SR	< 0.0053	0.29	0.0071	0.30	0.0091	0.18	0.0026
RB	< 0.0009	0.0088	< 0.0039	0.0088	0.0003	0.069	0.0010
BR	0.0010	< 0.14	< 0.021	0.0010 TO 0.16	< 0.0001 TO 0.0049	< 0.64	< 0.0092
SE	0.0019	< 0.027	< 0.22	0.0019 TO 0.24	< 0.0001 TO 0.0075	< 0.25	< 0.0037
AS	< 0.0098	0.047	< 0.013	0.047	0.0015	< 0.14	< 0.0020
GE	< 0.0015	< 0.022	< 0.0059	< 0.029	< 0.0009	< 0.18	< 0.0026
GA	< 0.0014	< 0.021	< 0.0032	< 0.026	< 0.0008	< 0.14	< 0.0020
ZN	0.038	< 4.7	< 0.19	0.038 TO 4.9	0.0012 TO 0.15	29.	0.42
CU	< 0.031	< 3.0	< 0.043	< 3.1	< 0.094	31.	0.45
NI	0.026	< 2.1	0.035	0.061 TO 2.1	0.0019 TO 0.064	4.5	0.064
CO	0.011	< 0.032	0.0047	0.016	0.0005	0.076	0.0011
FE	< 0.48	< 3.1	3.5	3.5	0.11	17.	0.24
MN	0.097	< 0.11	0.013	0.11	0.0034	0.41	0.0060
CR	0.016	< 0.22	0.049	0.065 TO 0.22	0.0020 TO 0.0068	1.8	0.026
V	< 0.0022	< 0.027	0.0013	0.0013 TO 0.030	< 0.0001 TO 0.0009	0.081	0.0012
TI	< 0.025	0.17	< 0.0022	0.17	0.0052	0.51	0.0073
CA	< 1.0	12.	0.96	13.	0.38	22.	0.32
K	< 0.61	< 10.	< 0.22	< 11.	< 0.33	11.	0.16
S	11.	< 34.	3.8	15. TO 34.	0.47 TO 1.0	140.	2.1
P	< 0.021	< 3.1	< 0.022	< 3.2	< 0.097	4.4	0.063
SI	< 0.13	< 4.3	0.14	0.14 TO 4.4	0.0044 TO 0.13	0.53 (%)	76.
AL	< 0.31	< 9.4	0.046	0.046 TO 9.7	0.0014 TO 0.30	14.	0.20
MG	< 0.22	3.0	0.20	3.2	0.098	51.	0.73
NA	< 6.1	10.	< 0.67	10.	0.31	300.	4.3
B	< 0.0084	< 6.4	0.0085	0.0085 TO 6.4	0.0003 TO 0.20	180.	2.5
BE	< 0.0001	0.0001	0.0002	0.0004	< 0.0001	0.0050	< 0.0001

SITE 306: VOLUME SAMPLED = 36.28 DSCM

TABLE D-7. SSMS DATA FOR DISTILLATE OIL-FUELED GAS TURBINES (SITE 306)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0039	< 0.089	< 0.022	< 0.11	< 0.0032	< 0.48	< 0.012
TH	< 0.0038	< 0.087	< 0.021	< 0.11	< 0.0031	< 0.46	< 0.011
BI	< 0.0034	< 0.078	< 0.019	< 0.100	< 0.0028	< 0.42	< 0.0100
PB	< 0.80	0.37	0.039	0.41	0.011	2.8	0.069
TL	< 0.0034	< 0.076	< 0.019	< 0.099	< 0.0027	< 0.41	< 0.0100
AU	< 0.0032	< 0.074	< 0.018	< 0.095	< 0.0026	< 0.39	< 0.0098
IR	< 0.0032	< 0.072	< 0.018	< 0.093	< 0.0026	< 0.38	< 0.0095
OS	< 0.0031	< 0.071	< 0.018	< 0.092	< 0.0025	< 0.38	< 0.0094
RE	< 0.0031	< 0.070	< 0.017	< 0.090	< 0.0025	< 0.37	< 0.0092
W	< 0.0064	< 0.069	< 0.017	< 0.092	< 0.0025	< 0.37	< 0.0091
HF	< 0.0029	< 0.067	< 0.016	< 0.086	< 0.0024	< 0.36	< 0.0088
LU	< 0.0029	< 0.065	< 0.016	< 0.084	< 0.0023	< 0.35	< 0.0087
YB	< 0.0028	< 0.065	< 0.016	< 0.084	< 0.0023	< 0.35	< 0.0086
TM	< 0.0028	< 0.063	< 0.016	< 0.082	< 0.0022	< 0.34	< 0.0084
ER	< 0.0028	< 0.063	< 0.015	< 0.081	< 0.0022	< 0.33	< 0.0083
HO	< 0.0027	< 0.062	< 0.015	< 0.080	< 0.0022	< 0.33	< 0.0082
DY	< 0.0027	< 0.061	< 0.015	< 0.078	< 0.0022	< 0.33	< 0.0080
TB	< 0.0026	< 0.059	< 0.015	< 0.077	< 0.0021	< 0.32	< 0.0079
GD	< 0.0026	< 0.058	< 0.015	< 0.076	< 0.0021	< 0.31	< 0.0078
EU	< 0.0025	< 0.057	< 0.014	< 0.073	< 0.0020	< 0.30	< 0.0075
SM	< 0.0025	< 0.056	< 0.014	< 0.073	< 0.0020	< 0.30	< 0.0074
ND	< 0.0024	< 0.054	0.0022	0.0022 TO 0.056	< 0.0001 TO 0.0016	< 0.29	< 0.0071
PR	< 0.0023	< 0.053	< 0.013	< 0.068	< 0.0019	< 0.28	< 0.0070
CE	0.0009	0.017	0.0015	0.019	0.0005	< 0.28	< 0.0069
LA	< 0.0011	0.0087	< 0.013	0.0087	0.0002	< 0.28	< 0.0069
BA	< 0.31	0.49	0.039	0.53	0.015	< 0.49	< 0.012
CS	< 0.0001	0.0014	< 0.0008	0.0014	< 0.0001	< 0.27	< 0.0066
I	0.0039	0.0100	0.0018	0.013	0.0004	0.040	0.0010
TE	< 0.0021	< 0.048	< 0.012	< 0.062	< 0.0017	< 0.26	< 0.0063
SB	< 0.0033	0.013	< 0.0066	0.013	0.0004	< 0.090	< 0.0022
SN	0.028	0.20	< 2.0	0.23 TO 2.0	0.0063 TO 0.054	5.5	0.14
CD	< 0.0043	0.031	0.011	0.042	0.0012	< 0.22	< 0.0056
PD	< 0.0018	< 0.040	< 0.0098	< 0.051	< 0.0014	< 0.21	< 0.0053
RH	< 0.0017	< 0.038	< 0.0095	< 0.050	< 0.0014	< 0.21	< 0.0051

- Continued -

SITE 306:   VOLUME SAMPLED = 36.28 DSCM

TABLE D-7 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0017	< 0.038	< 0.0093	< 0.049	< 0.0013	< 0.20	< 0.0050
MO	0.028	0.28	< 0.26	0.39	0.0084	0.17	0.0043
NB	< 0.0001	0.012	0.0001	0.012	0.0003	< 0.19	< 0.0046
ZR	0.015	0.091	0.0014	0.11	0.0030	< 0.18	< 0.0045
Y	0.0006	0.0052	< 0.0082	0.0038 TO 0.0082	< 0.0001 TO 0.0002	< 0.18	< 0.0044
SR	0.0060	0.17	< 0.0063	0.18	0.0049	0.099	0.0025
RB	0.0069	0.011	< 0.0021	0.012	0.0003	< 0.028	< 0.0007
BR	< 0.0044	0.29	0.0060	0.29	0.0081	< 0.35	< 0.0086
SE	0.054	0.030	< 0.065	0.083	0.0023	< 0.16	< 0.0039
AS	0.020	0.16	< 0.080	0.18	0.0050	< 0.21	< 0.0053
GE	0.0059	< 0.027	< 0.0067	0.0059 TO 0.034	0.0002 TO 0.0009	< 0.15	< 0.0036
GA	< 0.0011	< 0.026	< 0.0064	< 0.034	< 0.0009	< 0.14	< 0.0035
ZN	0.60	1.4	0.23	2.2	0.061	15.	0.36
CU	0.079	4.3	< 0.22	4.3	0.12	31.	0.76
NI	1.1	4.1	0.60	5.7	0.16	53.	1.3
CO	0.0057	0.058	0.018	0.082	0.0023	0.35	0.0086
FE	3.6	3.6	1.3	8.6	0.24	20.	0.50
MN	1.0	0.11	< 0.40	1.1	0.031	9.0	0.22
CR	0.25	0.44	0.49	1.2	0.033	0.56	0.014
V	0.0009	0.013	< 0.012	0.014	0.0004	0.47	0.012
TI	< 0.067	0.82	< 0.029	0.82	0.022	< 0.54	< 0.013
CA	1.8	5.7	< 1.4	7.5	0.21	27.	0.67
K	2.0	2.7	0.41	5.1	0.14	< 8.4	< 0.21
S	16.	110.	4.8	130.	3.5	480.	12.
P	0.95	1.2	< 0.77	2.1	0.058	11.	0.27
SI	12.	10.	< 2.6	23.	0.63	<120.	< 2.9
AL	< 0.82	< 23.	< 0.34	< 24.	< 0.66	2.8	0.070
MG	4.7	1.7	0.17	6.6	0.18	< 7.2	< 0.18
NA	< 4.6	< 9.0	< 14.	< 27.	< 0.75	< 21.	< 0.52
B	7.7	< 0.100	< 0.0048	7.7	0.21	< 0.72	< 0.018
BE	< 0.0025	< 0.0004	< 0.0001	< 0.0029	< 0.0001	< 0.0056	< 0.0001
LI	< 0.0082	0.0027	< 0.0005	0.0027 TO 0.0086	< 0.0001 TO 0.0002	0.017	0.0004

SITE 307: VOLUME SAMPLED = 30.89 DSCM

TABLE D-8. SSMS DATA FOR DISTILLATE OIL-FUELED GAS TURBINES (SITE 307)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0033	< 0.063	< 0.029	< 0.096	< 0.0031	< 0.48	< 0.015
TH	< 0.0032	< 0.062	< 0.028	< 0.093	< 0.0030	< 0.46	< 0.014
BI	< 0.0029	< 0.056	< 0.025	< 0.084	< 0.0027	< 0.42	< 0.013
PB	0.59	0.0030	0.11	0.71	0.023	< 2.2	< 0.068
TL	< 0.0028	< 0.054	< 0.025	< 0.082	< 0.0027	< 0.41	< 0.013
AU	< 0.0027	< 0.053	< 0.024	< 0.079	< 0.0026	< 0.39	< 0.012
IR	< 0.0027	< 0.051	< 0.023	< 0.077	< 0.0025	< 0.38	< 0.012
OS	< 0.0026	< 0.051	< 0.023	< 0.076	< 0.0025	< 0.38	< 0.012
RE	< 0.0026	< 0.050	< 0.023	< 0.075	< 0.0024	< 0.37	< 0.012
W	< 0.0002	< 0.049	< 0.022	< 0.072	< 0.0023	< 0.37	< 0.011
HF	< 0.0025	< 0.048	< 0.022	< 0.072	< 0.0023	< 0.36	< 0.011
LU	< 0.0024	< 0.047	< 0.021	< 0.070	< 0.0023	< 0.35	< 0.011
YB	< 0.0024	< 0.046	< 0.021	< 0.069	< 0.0022	< 0.35	< 0.011
TM	< 0.0023	< 0.045	< 0.020	< 0.068	< 0.0022	< 0.34	< 0.0100
ER	< 0.0023	< 0.045	< 0.020	< 0.067	< 0.0022	< 0.33	< 0.0100
HO	< 0.0023	< 0.044	< 0.020	< 0.066	< 0.0021	< 0.33	< 0.0100
DY	< 0.0022	< 0.043	< 0.020	< 0.065	< 0.0021	< 0.33	< 0.0100
TB	< 0.0022	< 0.042	< 0.019	< 0.064	< 0.0021	< 0.32	< 0.0099
GD	< 0.0022	< 0.042	< 0.019	< 0.063	< 0.0020	< 0.31	< 0.0098
EU	< 0.0021	< 0.041	< 0.018	< 0.061	< 0.0020	< 0.30	< 0.0094
SM	< 0.0021	< 0.040	< 0.018	< 0.060	< 0.0020	< 0.30	< 0.0093
ND	< 0.0020	< 0.038	< 0.017	< 0.058	< 0.0019	< 0.29	< 0.0089
PR	< 0.0019	< 0.038	< 0.017	< 0.057	< 0.0018	< 0.28	< 0.0087
CE	< 0.0002	< 0.037	< 0.0034	< 0.041	< 0.0013	< 0.28	< 0.0087
LA	< 0.0002	< 0.037	< 0.017	< 0.054	< 0.0018	< 0.28	< 0.0086
BA	< 0.026	< 0.0034	0.016	0.016	0.0005	< 0.21	< 0.0065
CS	< 0.0001	< 0.035	0.0001	0.0001 TO 0.035	< 0.0001 TO 0.0011	< 0.27	< 0.0082
I	0.0003	< 0.034	< 0.015	0.0003 TO 0.049	< 0.0001 TO 0.0016	0.40	0.013
TE	< 0.0018	< 0.034	< 0.015	< 0.051	< 0.0017	< 0.26	< 0.0079
SB	< 0.0006	< 0.0003	< 0.0036	< 0.0046	< 0.0001	0.12	0.0038
SN	0.0054	< 0.0017	< 0.73	0.0054 TO 0.73	0.0002 TO 0.024	< 0.45	< 0.014
CD	0.0082	< 0.030	< 0.032	0.0082 TO 0.062	0.0003 TO 0.0020	< 0.22	< 0.0070
PD	< 0.0015	< 0.028	< 0.013	< 0.043	< 0.0014	< 0.21	< 0.0066
RH	< 0.0014	< 0.027	< 0.012	< 0.041	< 0.0013	< 0.21	< 0.0064

- Continued -

SITE 307: VOLUME SAMPLED = 30.89 DSCM

TABLE D-8 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0014	< 0.027	< 0.012	< 0.041	< 0.0013	< 0.20	< 0.0063
MO	0.023	< 0.0004	0.096	0.12	0.0039	0.14	0.0043
NB	< 0.0001	< 0.025	< 0.011	< 0.036	< 0.0012	0.020	0.0006
ZR	0.0044	< 0.024	< 0.0030	0.0044 TO 0.027	0.0001 TO 0.0009	< 0.18	< 0.0057
Y	< 0.0001	< 0.024	0.0006	0.0007 TO 0.024	< 0.0001 TO 0.0008	< 0.18	< 0.0055
SR	0.0020	< 0.0016	0.0089	0.011	0.0003	< 0.14	< 0.0043
RB	< 0.0005	< 0.0001	0.0034	0.0034	0.0001	< 0.024	< 0.0007
BR	< 0.0035	< 0.0021	< 0.0093	< 0.015	< 0.0005	< 0.29	< 0.0090
SE	0.032	< 0.021	0.022	0.054	0.0018	< 0.16	< 0.0049
AS	0.0100	< 0.0010	< 0.048	0.0100 TO 0.049	0.0003 TO 0.0016	< 0.13	< 0.0040
GE	< 0.0010	< 0.019	< 0.0088	< 0.029	< 0.0009	< 0.15	< 0.0045
GA	< 0.0010	< 0.019	< 0.0084	< 0.028	< 0.0009	< 0.14	< 0.0043
ZN	0.29	< 0.26	< 0.36	0.29 TO 0.62	0.0094 TO 0.020	< 9.6	< 0.30
CU	< 0.066	< 0.26	0.088	0.088 TO 0.33	0.0028 TO 0.011	31.	0.95
NI	< 0.017	< 0.0023	1.1	1.1	0.034	22.	0.68
CO	< 0.0040	< 0.0004	0.020	0.020	0.0006	0.18	0.0057
FE	< 1.4	< 0.12	1.0	1.0	0.033	< 17.	< 0.52
MN	0.14	< 0.0100	< 0.21	0.14	0.0046	16.	0.51
CR	0.086	< 0.0100	0.15	0.23	0.0075	0.72	0.022
V	0.0004	< 0.0005	< 0.015	0.0004 TO 0.015	< 0.0001 TO 0.0005	0.13	0.0041
TI	< 0.040	0.0008	0.017	0.018 TO 0.040	0.0006 TO 0.0013	< 0.32	< 0.0100
CA	< 0.64	< 0.54	< 2.5	< 3.7	< 0.12	< 5.1	< 0.16
K	< 0.34	< 0.93	< 0.45	< 1.7	< 0.056	< 5.1	< 0.16
S	< 0.81	< 7.3	< 4.6	< 13.	< 0.41	210.	6.5
P	0.19	< 0.61	0.097	0.29 TO 0.61	0.0093 TO 0.020	< 2.2	< 0.069
SI	< 0.071	< 1.5	< 4.6	< 6.2	< 0.20	< 69.	< 2.2
AL	< 0.0019	14.	0.17	14.	0.45	< 2.4	< 0.076
MG	< 0.025	< 1.1	< 0.16	< 1.3	< 0.042	< 3.0	< 0.094
NA	< 0.038	16.	< 3.6	16.	0.51	< 22.	< 0.68
B	< 0.22	< 0.60	0.014	0.014 TO 0.82	0.0005 TO 0.027	< 0.11	< 0.0034
BE	< 0.0001	< 0.037	< 0.0001	< 0.0001 TO 0.037	< 0.0001 TO 0.0012	< 0.0067	< 0.0002
LI	< 0.0002	0.0022	< 0.0027	0.0022	< 0.0001	< 0.023	< 0.0007

TABLE D-9. SSMS DATA FOR DISTILLATE OIL-FUELED GAS TURBINES (SITE 308)

SITE 308: VOLUME SAMPLED = 30.02 DSCM

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL CA (PPM)	EMISSIOM LCULAT ED (MG/DSCM)
U	< 0.0040	< 0.048	< 0.027	< 0.079	< 0.0026	< 0.48	< 0.0088
TH	< 0.0039	< 0.047	< 0.026	< 0.077	< 0.0026	< 0.46	< 0.0086
BI	0.0018	< 0.042	< 0.024	0.0018 TO 0.066	< 0.0001 TO 0.0022	< 0.42	< 0.0078
PB	< 0.80	0.51	< 0.057	0.51	0.017	4.0	0.075
TL	< 0.0035	< 0.041	< 0.023	< 0.068	< 0.0023	< 0.41	< 0.0076
AU	< 0.0033	< 0.040	< 0.022	< 0.065	< 0.0022	< 0.39	< 0.0073
IR	< 0.0033	< 0.039	< 0.022	< 0.064	< 0.0021	< 0.38	< 0.0071
OS	< 0.0032	< 0.041	< 0.022	< 0.066	< 0.0022	< 0.38	< 0.0071
RE	< 0.0032	< 0.038	< 0.021	< 0.062	< 0.0021	< 0.37	< 0.0069
W	< 0.0007	< 0.037	< 0.021	< 0.059	< 0.0020	< 0.37	< 0.0068
HF	< 0.0030	< 0.043	< 0.020	< 0.066	< 0.0022	< 0.36	< 0.0066
LU	< 0.0030	< 0.035	< 0.020	< 0.058	< 0.0019	< 0.35	< 0.0065
YB	< 0.0029	< 0.035	< 0.020	< 0.057	< 0.0019	< 0.35	< 0.0064
TM	< 0.0029	< 0.034	< 0.019	< 0.056	< 0.0019	< 0.34	< 0.0063
ER	< 0.0028	< 0.034	< 0.019	< 0.056	< 0.0019	< 0.33	< 0.0062
HO	< 0.0028	< 0.033	< 0.019	< 0.055	< 0.0018	< 0.33	< 0.0061
DY	< 0.0028	< 0.033	< 0.018	< 0.054	< 0.0018	< 0.33	< 0.0060
TB	< 0.0027	< 0.032	< 0.018	< 0.053	< 0.0018	< 0.32	< 0.0059
GD	< 0.0027	< 0.032	< 0.018	< 0.052	< 0.0017	< 0.31	< 0.0058
EU	< 0.0026	< 0.031	< 0.017	< 0.050	< 0.0017	< 0.30	< 0.0056
SM	< 0.0026	< 0.030	< 0.017	< 0.050	< 0.0017	< 0.30	< 0.0056
ND	< 0.0025	< 0.033	< 0.016	< 0.052	< 0.0017	< 0.29	< 0.0053
PR	< 0.0024	< 0.028	< 0.0003	< 0.031	< 0.0010	< 0.28	< 0.0052
CE	< 0.0024	< 0.028	< 0.0021	< 0.033	< 0.0011	< 0.28	< 0.0052
LA	< 0.0024	< 0.028	< 0.016	< 0.046	< 0.0015	< 0.28	< 0.0052
BA	< 0.27	< 0.39	< 0.013	< 0.67	< 0.022	< 0.40	< 0.0074
CS	< 0.0001	< 0.027	< 0.0003	< 0.027	< 0.0009	< 0.27	< 0.0049
I	0.0019	< 0.026	< 0.013	0.0019 TO 0.038	< 0.0001 TO 0.0013	< 0.25	< 0.0047
TE	< 0.0022	< 0.026	< 0.014	< 0.042	< 0.0014	< 0.26	< 0.0047
SB	< 0.0030	< 0.025	< 0.0035	< 0.031	< 0.0010	6.4	0.12
SN	2.1	< 0.050	< 0.47	2.1	0.071	0.46	0.0085
CD	< 0.0089	0.023	0.13	0.15	0.0051	< 0.22	< 0.0042
PD	< 0.0018	< 0.021	< 0.012	< 0.035	< 0.0012	< 0.21	< 0.0039
RH	< 0.0017	< 0.021	< 0.012	< 0.034	< 0.0011	< 0.21	< 0.0038

- Continued -

SITE 308: VOLUME SAMPLED = 30.02 DSCM

TABLE D-9 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSIOM CA LCULAT ED (MG/DSCM)
RU	< 0.0017	< 0.024	< 0.011	< 0.037	< 0.0012	< 0.20	< 0.0038
MO	0.013	< 0.064	< 0.042	0.013 TO 0.11	0.0004 TO 0.0035	0.32	0.0059
NB	< 0.0001	< 0.019	0.0003	0.0003 TO 0.019	< 0.0001 TO 0.0006	0.028	0.0005
ZR	< 0.014	< 0.018	< 0.0006	< 0.033	< 0.0011	0.11	0.0021
Y	0.0001	< 0.018	< 0.0100	0.0001 TO 0.028	< 0.0001 TO 0.0009	< 0.18	< 0.0033
SR	0.014	< 0.13	< 0.0100	0.014 TO 0.14	0.0005 TO 0.0046	0.066	0.0012
RB	0.0009	< 0.0078	0.0009	0.0018 TO 0.0078	< 0.0001 TO 0.0003	< 0.032	< 0.0006
BR	< 0.0079	0.048	< 0.0018	0.048	0.0016	< 0.57	< 0.011
SE	0.052	< 0.016	< 0.0047	0.052	0.0017	< 0.16	< 0.0029
AS	0.0081	0.027	0.024	0.060	0.0020	< 0.35	< 0.0065
GE	< 0.0012	< 0.015	< 0.0082	< 0.024	< 0.0008	< 0.15	< 0.0027
GA	< 0.0012	< 0.014	< 0.0079	< 0.023	< 0.0008	< 0.14	< 0.0026
ZN	0.42	< 2.0	< 0.50	0.42 TO 2.5	0.014 TO 0.084	4.6	0.085
CU	< 0.13	1.0	< 0.11	1.0	0.034	42.	0.78
NI	< 0.29	< 2.0	0.11	0.11 TO 2.2	0.0037 TO 0.075	43.	0.79
CO	< 0.0023	< 0.030	< 0.021	< 0.053	< 0.0018	0.27	0.0049
FE	< 0.45	< 3.0	0.46	0.46 TO 3.4	0.015 TO 0.11	< 22.	< 0.42
MN	0.015	0.12	< 0.13	0.13	0.0043	< 0.40	< 0.0075
CR	0.031	< 0.39	< 0.12	0.031 TO 0.50	0.0010 TO 0.017	1.5	0.029
V	< 0.0020	0.37	< 0.0018	0.37	0.012	< 0.053	< 0.0010
TI	< 0.066	< 0.036	0.0051	0.0051 TO 0.100	0.0002 TO 0.0034	< 0.21	< 0.0039
CA	< 1.3	< 23.	< 1.5	< 26.	< 0.86	9.8	0.18
K	< 0.48	3.5	< 0.39	3.5	0.12	< 6.8	< 0.13
S	7.6	41.	4.3	53.	1.8	130.	2.4
P	< 0.070	< 2.1	0.077	0.077 TO 2.1	0.0026 TO 0.071	< 4.3	< 0.079
SI	< 5.5	< 5.7	< 3.0	< 14.	< 0.47	< 23.	< 0.43
AL	< 0.45	< 4.4	< 0.25	< 5.1	< 0.17	< 4.3	< 0.079
MG	< 0.34	2.5	< 0.15	2.5	0.083	< 2.9	< 0.053
NA	5.0	14.	1.6	21.	0.68	< 50.	< 0.93
B	< 0.062	1.4	< 0.0012	1.4	0.047	< 0.58	< 0.011
BE	< 0.0001	< 0.0007	< 0.0001	< 0.0008	< 0.0001	< 0.018	< 0.0003
LI	< 0.0004	0.087	0.0017	0.089	0.0030	< 0.022	< 0.0004

TABLE D-10. SASS TRAIN DISTRIBUTION FOR SPECIFIC INORGANICS, DISTILLATE OIL RECIPROCATING ENGINE (SITES 309, 310, 311, 312, 313)

Site	Species	Particulate (mg)	XAD-2 (mg)	Impingers		Total Catch (mg)	Found Mass Emissions (mg/DSCM)	Fuel Feed (μg/g)	Calculated Mass Emissions (mg/DSCM)
				Composite† (mg)	APS‡ (mg)				
309	Hg	<.00004	.0047	<.0013	<.022	.0047	.00016	.003	.00013
	As	<.0009	<.0025	-	*	<.0034	<.00012	<.098	<.0040
	Sb	<.0009	<.0025	<.0013	<.0011	<.0058	<.00020	.29	.013
	SO_4	21.2	10.5	-	-	31.7	1.1**	7000.	302.
310	Hg	<.00001	.0022	<.0066	<.022	.0022	.00077	.009	.00028
	As	<.00063	<.0024	<.0017	*	<.0047	<.00017	<.10	<.0032
	Sb	<.00035	<.051	<.0017	<.0011	<.054	<.0019	<.10	<.0032
	SO_4	20.8	44.0	-	-	65.	2.3**	7400.	227.
311	Hg	<.00005	<.00053	<.0018	<.024	<.027	<.00091	.007	.00015
	As	<.00073	<.0032	<.0018	*	<.0057	<.00020	<.10	<.0022
	Sb	<.00073	<.0032	<.0018	<.0012	<.0069	<.00024	<.10	<.0022
	SO_4	28.5	82.4	-	-	111.	3.8**	7700.	162.
312	Hg	<.00001	.00098	<.0016	<.0021	.00098	.00003	.007	.00029
	As	<.00056	<.0011	<.0016	*	<.0033	<.00011	<.10	<.004
	Sb	.0039	<.0011	<.0016	<.0011	<.0077	<.00030	<.10	<.004
	SO_4	15.	104.	-	-	119.	4.**	4500.	190.
313	Hg	<.00001	<.00042	<.0048	<.027	<.032	<.0011	.004	.00012
	As	<.00071	<.0011	<.0016	*	<.0034	<.00011	<.10	<.003
	Sb	.0017	<.0011	<.0016	<.0014	.0017	.00006	2.0	.0057
	SO_4	22.1	122	-	-	144	4.8**	5000.	151.

*Not determined due to interference of isopropanol.

†Composite of HNO_3 module wash, condensate, and the H_2O_2 impinger.

‡The second impinger containing ammonium persulfate (APS) and silver nitrate and the third impinger containing APS.

**SO_4 values do not represent total sulfur in the SASS train.

SITE 309: VOLUME SAMPLED = 28.50 DSCM

TABLE D-11. SSMS DATA FOR DISTILLATE OIL RECIPROCATING ENGINE (SITE 309)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.013	< 0.100	< 0.031	< 0.14	< 0.0051	< 0.48	< 0.020
TH	< 0.019	< 0.098	< 0.030	< 0.15	< 0.0052	< 0.46	< 0.020
BI	< 0.0057	< 0.089	< 0.027	< 0.12	< 0.0043	< 0.42	< 0.018
PB	< 0.28	0.81	0.068	0.88	0.031	1.5	0.062
TL	< 0.0072	< 0.087	< 0.027	< 0.12	< 0.0042	< 0.41	< 0.017
AU	< 0.0096	< 0.084	< 0.026	< 0.12	< 0.0042	< 0.39	< 0.017
IR	< 0.015	< 0.081	< 0.025	< 0.12	< 0.0043	< 0.38	< 0.016
OS	< 0.016	< 0.081	< 0.025	< 0.12	< 0.0043	< 0.38	< 0.016
RE	< 0.0100	< 0.079	< 0.024	< 0.11	< 0.0040	< 0.37	< 0.016
W	0.0073	< 0.078	< 0.024	0.0073 TO 0.100	0.0003 TO 0.0036	< 0.37	< 0.016
HF	< 0.017	< 0.076	< 0.023	< 0.12	< 0.0041	< 0.36	< 0.015
LU	< 0.0040	< 0.074	< 0.023	< 0.100	< 0.0035	< 0.35	< 0.015
YB	< 0.0058	< 0.073	< 0.023	< 0.100	< 0.0036	< 0.35	< 0.015
TM	< 0.0035	< 0.072	< 0.022	< 0.097	< 0.0034	< 0.34	< 0.014
ER	< 0.0100	< 0.071	< 0.022	< 0.100	< 0.0036	< 0.33	< 0.014
HO	< 0.0034	< 0.070	< 0.022	< 0.095	< 0.0033	< 0.33	< 0.014
DY	< 0.0059	< 0.069	< 0.021	< 0.096	< 0.0034	< 0.33	< 0.014
TB	< 0.0022	< 0.067	< 0.021	< 0.090	< 0.0032	< 0.32	< 0.014
GD	< 0.0059	< 0.067	< 0.021	< 0.093	< 0.0033	< 0.31	< 0.013
EU	< 0.0027	< 0.064	< 0.020	< 0.087	< 0.0031	< 0.30	< 0.013
SM	< 0.0100	< 0.064	< 0.020	< 0.094	< 0.0033	< 0.30	< 0.013
ND	< 0.013	< 0.061	< 0.019	< 0.093	< 0.0033	< 0.29	< 0.012
PR	< 0.0023	< 0.060	< 0.018	< 0.080	< 0.0028	< 0.28	< 0.012
CE	< 0.0031	< 0.027	< 0.0022	< 0.032	< 0.0011	0.012	0.0005
LA	< 0.0033	< 0.0099	< 0.018	< 0.031	< 0.0011	< 0.28	< 0.012
BA	0.47	< 0.23	0.018	0.49	0.017	0.21	0.0090
CS	0.018	0.0014	< 0.017	0.019	0.0007	0.016	0.0007
I	< 0.0088	0.11	< 0.017	0.11	0.0039	0.032	0.0014
TE	< 0.0074	< 0.054	< 0.017	< 0.078	< 0.0027	< 0.26	< 0.011
SB	0.013	< 0.030	< 0.0049	0.013 TO 0.035	0.0004 TO 0.0012	0.27	0.011
SN	0.078	0.052	< 0.88	0.13 TO 0.88	0.0046 TO 0.031	0.29	0.012
CD	< 0.0092	0.11	0.068	0.18	0.0063	< 0.15	< 0.0063
PD	< 0.0074	< 0.045	< 0.014	< 0.066	< 0.0023	< 0.21	< 0.0091
RH	< 0.0026	< 0.044	< 0.013	< 0.060	< 0.0021	< 0.21	< 0.0088

-Continued-

SITE 309:   VOLUME SAMPLED = 28.50 DSCM

TABLE D-11 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0095	< 0.043	< 0.013	< 0.066	< 0.0023	< 0.20	< 0.0086
MO	0.15	< 0.053	0.087	0.23	0.0082	1.5	0.062
NB	< 0.0016	< 0.0066	< 0.012	< 0.020	< 0.0007	0.063	0.0027
ZR	0.065	< 0.018	< 0.012	0.065	0.0023	< 0.18	< 0.0078
Y	0.0008	< 0.038	< 0.012	0.0008 TO 0.049	< 0.0001 TO 0.0017	< 0.18	< 0.0076
SR	0.096	< 0.11	0.27	0.36	0.013	< 0.092	< 0.0039
RB	0.032	0.0056	< 0.0011	0.038	0.0013	< 0.045	< 0.0019
BR	0.012	0.28	< 0.0093	0.29	0.0100	< 0.39	< 0.016
SE	0.046	< 0.033	< 0.0100	0.046	0.0016	< 0.67	< 0.029
AS	0.065	0.042	< 0.0083	0.11	0.0038	< 0.17	< 0.0073
GE	< 0.0035	< 0.031	< 0.0095	< 0.044	< 0.0015	< 0.15	< 0.0062
GA	< 0.0014	< 0.030	< 0.0091	< 0.040	< 0.0014	< 0.14	< 0.0059
ZN	< 0.23	1.7	2.0	3.7	0.13	6.6	0.28
CU	0.24	2.3	0.094	2.6	0.091	29.	1.2
NI	3.9	< 4.4	0.71	4.6	0.16	43.	1.8
CO	0.043	0.028	13.	13.	0.44	0.27	0.011
FE	40.	5.2	2.1	48.	1.7	< 22.	< 0.94
MN	0.76	0.28	0.081	1.1	0.039	0.94	0.040
CR	0.47	< 0.54	0.65	1.1	0.039	1.5	0.064
V	0.0046	0.071	< 0.0072	0.076	0.0027	0.035	0.0015
TI	0.100	< 0.062	0.0100	0.11	0.0040	< 0.43	< 0.018
CA	7.4	2.9	23.	34.	1.2	< 8.0	< 0.34
K	1.7	3.8	0.22	5.7	0.20	< 24.	< 1.0
S	31.	140.	44.	210.	7.4	280.	12.
P	4.0	1.5	0.11	5.7	0.20	< 4.2	< 0.18
SI	100.	14.	< 2.2	120.	4.1	< 33.	< 1.4
AL	2.6	< 2.6	0.79	3.4	0.12	2.8	0.12
MG	3.5	16.	0.15	19.	0.68	< 4.1	< 0.17
NA	9.6	22.	1.7	33.	1.2	50.	2.1
B	1.8	0.63	0.024	2.4	0.086	< 1.5	< 0.065
BE	< 0.0001	0.0018	< 0.0001	0.0019	< 0.0001	< 0.048	< 0.0020

SITE 310: VOLUME SAMPLED = 28.63 DSCM

TABLE D-12. SSMS DATA FOR DISTILLATE OIL RECIPROCATING ENGINE (SITE 310)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0040	< 0.058	< 0.039	< 0.100	< 0.0035	< 0.48	< 0.015
TH	< 0.0039	< 0.056	< 0.038	< 0.098	< 0.0034	< 0.46	< 0.015
BI	< 0.0035	< 0.050	< 0.035	< 0.089	< 0.0031	< 0.42	< 0.013
PB	0.23	0.87	< 0.050	1.1	0.038	< 5.1	< 0.16
TL	< 0.0034	< 0.049	< 0.034	< 0.087	< 0.0030	< 0.41	< 0.013
AU	< 0.0033	< 0.048	< 0.033	< 0.083	< 0.0029	< 0.39	< 0.012
IR	< 0.0032	< 0.046	< 0.032	< 0.081	< 0.0028	< 0.38	< 0.012
OS	< 0.0032	< 0.046	< 0.031	< 0.081	< 0.0028	< 0.38	< 0.012
RE	< 0.0031	< 0.045	< 0.031	< 0.079	< 0.0028	< 0.37	< 0.012
W	< 0.0031	< 0.044	< 0.030	< 0.078	< 0.0027	< 0.37	< 0.012
HF	< 0.0030	< 0.043	< 0.030	< 0.076	< 0.0026	< 0.36	< 0.011
LU	< 0.0029	< 0.042	< 0.029	< 0.074	< 0.0026	< 0.35	< 0.011
YB	< 0.0029	< 0.042	< 0.029	< 0.073	< 0.0026	< 0.35	< 0.011
TM	< 0.0028	< 0.041	< 0.028	< 0.072	< 0.0025	< 0.34	< 0.011
ER	< 0.0028	< 0.040	< 0.028	< 0.071	< 0.0025	< 0.33	< 0.011
HO	< 0.0027	< 0.040	< 0.027	< 0.070	< 0.0024	< 0.33	< 0.0100
DY	< 0.0027	< 0.039	< 0.027	< 0.069	< 0.0024	< 0.33	< 0.0100
TB	< 0.0026	< 0.038	< 0.026	< 0.067	< 0.0024	< 0.32	< 0.0100
GD	< 0.0026	< 0.038	< 0.026	< 0.067	< 0.0023	< 0.31	< 0.0099
EU	< 0.0025	< 0.037	< 0.025	< 0.064	< 0.0022	< 0.30	< 0.0095
SM	< 0.0025	< 0.036	< 0.025	< 0.064	< 0.0022	< 0.30	< 0.0094
ND	< 0.0024	< 0.035	< 0.024	< 0.061	< 0.0021	< 0.29	< 0.0091
PR	< 0.0023	< 0.034	< 0.023	< 0.060	< 0.0021	< 0.28	< 0.0089
CE	< 0.0006	0.0047	< 0.0011	0.0047	0.0002	0.046	0.0014
LA	< 0.0007	< 0.034	< 0.023	< 0.057	< 0.0020	< 0.28	< 0.0087
BA	< 0.044	0.090	< 0.014	0.090	0.0031	< 0.70	< 0.022
CS	< 0.0001	< 0.032	< 0.022	< 0.054	< 0.0019	0.0099	0.0003
I	0.0007	0.028	< 0.0045	0.028	0.0010	< 0.25	< 0.0080
TE	< 0.0021	< 0.031	< 0.021	< 0.054	< 0.0019	< 0.26	< 0.0080
SB	0.0018	< 0.029	< 0.0071	0.0018 TO 0.056	< 0.0001 TO 0.0013	< 0.064	< 0.0020
SN	0.0071	0.096	1.2	1.3	0.047	< 0.51	< 0.016
CD	< 0.0019	0.059	0.0073	0.066	0.0023	< 0.22	< 0.0071
PD	< 0.0018	< 0.026	< 0.018	< 0.045	< 0.0016	< 0.21	< 0.0067
RH	< 0.0017	< 0.025	< 0.017	< 0.044	< 0.0015	< 0.21	< 0.0065

- Continued -

SITE 310: VOLUME SAMPLED = 28.65 DSCM

TABLE D-12 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0017	< 0.024	< 0.017	< 0.045	< 0.0015	< 0.20	< 0.0064
MO	0.0096	0.056	< 0.037	0.066	0.0023	0.61	0.019
NB	< 0.0015	< 0.022	< 0.015	< 0.039	< 0.0014	0.054	0.0017
ZR	0.0058	< 0.022	< 0.015	0.0058 TO 0.037	0.0002 TO 0.0013	< 0.18	< 0.0057
Y	0.0002	< 0.021	< 0.015	0.0002 TO 0.036	< 0.0001 TO 0.0013	< 0.18	< 0.0056
SR	0.013	0.039	< 0.0064	0.052	0.0018	< 0.16	< 0.0051
RB	0.0016	0.0071	< 0.0004	0.0087	0.0003	0.097	0.0030
BR	< 0.023	0.066	< 0.013	0.066	0.0023	< 0.49	< 0.015
SE	< 0.0013	< 0.019	< 0.033	< 0.053	< 0.0019	< 0.16	< 0.0050
AS	0.0085	< 0.051	< 0.0010	0.0085 TO 0.052	0.0003 TO 0.0018	< 0.43	< 0.013
GE	< 0.0012	< 0.018	< 0.012	< 0.031	< 0.0011	< 0.15	< 0.0046
GA	< 0.0012	< 0.017	< 0.012	< 0.030	< 0.0010	< 0.14	< 0.0044
ZN	0.44	< 2.5	0.31	0.75 TO 2.5	0.026 TO 0.086	9.7	0.30
CU	0.043	1.7	0.074	1.8	0.063	24.	0.76
NI	0.83	0.84	0.30	2.0	0.069	19.	0.58
CO	< 0.0036	0.0085	< 0.023	0.0085 TO 0.026	0.0003 TO 0.0009	0.36	0.011
FE	< 0.32	1.2	< 2.2	1.2 TO 2.5	0.041 TO 0.088	< 21.	< 0.66
MN	< 0.0080	0.039	0.11	0.15	0.0051	1.2	0.038
CR	0.032	0.25	0.15	0.43	0.015	2.1	0.065
V	< 0.0015	0.081	< 0.0026	0.081	0.0028	0.11	0.0036
TI	< 0.050	0.064	< 0.0072	0.064	0.0022	< 0.37	< 0.012
CA	3.4	< 10.	< 3.9	3.4 TO 14.	0.12 TO 0.49	3.3	0.100
K	< 0.65	4.2	< 0.33	4.2	0.15	< 17.	< 0.53
S	42.	< 41.	6.7	48.	1.7	0.15 (%)	47.
P	0.39	< 1.3	< 0.69	0.39 TO 1.9	0.014 TO 0.068	6.0	0.19
SI	< 3.5	< 2.4	< 1.1	< 7.0	< 0.25	< 32.	< 0.99
AL	< 0.62	2.8	0.60	3.4	0.12	< 4.5	< 0.14
MG	< 0.79	0.79	0.34	1.1	0.039	< 5.0	< 0.16
NA	12.	13.	< 3.1	24.	0.85	23.	0.71
B	< 0.42	0.32	< 0.014	0.32	0.011	< 0.49	< 0.015
BE	< 0.0007	0.0002	< 0.0015	0.0002 TO 0.0022	< 0.0001 TO 0.0001	-0.0014	< 0.0001
LI	< 0.0037	0.012	0.0004	0.012	0.0004	0.15	0.0046

TABLE D-13. SSMS DATA FOR DISTILLATE OIL RECIPROCATING ENGINE (SITE 311)

SITE 311: VOLUME SAMPLED = 28.90 DSCM

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0032	< 0.051	< 0.044	< 0.098	< 0.0034	< 0.48	< 0.011
TH	< 0.0031	< 0.050	< 0.043	< 0.096	< 0.0033	< 0.46	< 0.0100
BI	< 0.0028	< 0.045	< 0.038	< 0.086	< 0.0030	< 0.42	< 0.0093
PB	< 0.25	0.097	< 0.16	0.097 TO 0.41	0.0033 TO 0.014	< 1.6	< 0.036
TL	< 0.0028	< 0.044	< 0.038	< 0.084	< 0.0029	< 0.41	< 0.0091
AU	< 0.0027	< 0.043	< 0.036	< 0.081	< 0.0028	< 0.39	< 0.0088
IR	< 0.0026	< 0.042	< 0.035	< 0.079	< 0.0027	< 0.38	< 0.0086
OS	< 0.0026	< 0.041	< 0.035	< 0.079	< 0.0027	< 0.38	< 0.0085
RE	< 0.0025	< 0.040	< 0.034	< 0.077	< 0.0027	< 0.37	< 0.0083
W	< 0.0025	< 0.040	< 0.034	< 0.076	< 0.0026	< 0.37	< 0.0082
HF	< 0.0024	< 0.039	< 0.033	< 0.074	< 0.0026	< 0.36	< 0.0080
LU	< 0.0024	< 0.038	< 0.032	< 0.072	< 0.0025	< 0.35	< 0.0078
YB	< 0.0023	< 0.037	< 0.032	< 0.071	< 0.0025	< 0.35	< 0.0077
TM	< 0.0023	< 0.036	< 0.031	< 0.070	< 0.0024	< 0.34	< 0.0075
ER	< 0.0023	< 0.036	< 0.031	< 0.069	< 0.0024	< 0.33	< 0.0075
HO	< 0.0022	< 0.036	< 0.030	< 0.068	< 0.0024	< 0.33	< 0.0074
DY	< 0.0022	< 0.035	< 0.030	< 0.067	< 0.0023	< 0.33	< 0.0073
TB	< 0.0021	< 0.034	< 0.029	< 0.066	< 0.0023	< 0.32	< 0.0071
GD	< 0.0021	< 0.034	< 0.029	< 0.065	< 0.0022	< 0.31	< 0.0070
EU	< 0.0021	< 0.033	< 0.028	< 0.063	< 0.0022	< 0.30	< 0.0068
SM	< 0.0020	< 0.032	< 0.028	< 0.062	< 0.0022	< 0.30	< 0.0067
ND	< 0.0019	< 0.031	< 0.026	< 0.060	< 0.0021	< 0.29	< 0.0064
PR	< 0.0019	< 0.030	< 0.026	< 0.058	< 0.0020	< 0.28	< 0.0063
CE	< 0.0019	< 0.030	0.0009	0.0009 TO 0.032	< 0.0001 TO 0.0011	< 0.035	< 0.0008
LA	< 0.0019	< 0.030	< 0.026	< 0.057	< 0.0020	0.0045	0.0002
BA	< 0.070	< 1.1	< 0.021	< 1.2	< 0.042	< 0.62	< 0.014
CS	< 0.0018	< 0.029	< 0.024	< 0.055	< 0.0019	0.0031	< 0.0001
I	< 0.0017	< 0.027	< 0.0071	< 0.036	< 0.0013	0.100	0.0023
TE	< 0.0017	< 0.028	< 0.023	< 0.053	< 0.0018	< 0.26	< 0.0057
SB	0.0040	< 0.054	< 0.0078	0.0040 TO 0.062	0.0001 TO 0.0021	0.44	0.0098
SN	< 0.0100	< 0.055	< 2.0	< 2.1	< 0.071	0.32	0.0071
CD	< 0.0018	< 0.100	0.017	0.017 TO 0.11	0.0006 TO 0.0037	< 0.085	< 0.0019
PD	< 0.0014	< 0.023	< 0.020	< 0.044	< 0.0015	< 0.21	< 0.0047
RH	< 0.0014	< 0.022	< 0.019	< 0.043	< 0.0015	< 0.21	< 0.0046

- Continued -

SITE 311: VOLUME SAMPLED = 28.90 DSCM

TABLE D-13 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0014	< 0.022	< 0.019	< 0.042	< 0.0014	< 0.20	< 0.0045
MO	< 0.0043	< 0.034	< 0.015	< 0.053	< 0.0018	0.14	0.0032
NB	< 0.0003	< 0.020	< 0.017	< 0.037	< 0.0013	< 0.018	< 0.0004
ZR	0.0082	< 0.020	< 0.017	0.0082 TO 0.036	0.0003 TO 0.0013	< 0.034	< 0.0007
Y	< 0.0012	< 0.019	< 0.016	< 0.037	< 0.0013	< 0.18	< 0.0040
SR	0.0052	< 0.069	< 0.0100	0.0052 TO 0.079	0.0002 TO 0.0027	< 0.20	< 0.0045
RB	< 0.0004	< 0.017	< 0.0012	< 0.018	< 0.0006	0.033	0.0007
BR	< 0.0015	< 0.41	< 0.0074	< 0.42	< 0.015	< 0.30	< 0.0068
SE	< 0.0011	< 0.017	< 0.015	< 0.033	< 0.0011	< 0.19	< 0.0042
AS	0.0020	< 0.032	< 0.0047	0.0020 TO 0.037	< 0.0001 TO 0.0013	< 0.27	< 0.0060
GE	< 0.0010	< 0.016	< 0.013	< 0.030	< 0.0010	< 0.15	< 0.0032
GA	< 0.0009	< 0.015	< 0.013	< 0.029	< 0.0010	< 0.14	< 0.0031
ZN	0.21	2.3	< 1.7	2.5	0.088	< 4.5	< 0.100
CU	< 0.075	< 1.7	< 0.31	< 2.1	< 0.073	19.	0.41
NI	0.31	< 2.2	< 0.43	0.31 TO 2.6	0.011 TO 0.091	28.	0.62
CO	< 0.0021	0.011	< 0.025	0.011 TO 0.027	0.0004 TO 0.0009	0.45	0.0099
FE	< 0.20	7.4	< 2.4	7.4	0.26	9.5	0.21
MN	< 0.0035	0.11	< 0.34	0.11 TO 0.34	0.0038 TO 0.012	0.24	0.0052
CR	0.0074	< 0.079	< 0.19	0.0074 TO 0.27	0.0003 TO 0.0094	0.59	0.013
V	< 0.0009	< 0.0070	< 0.0041	< 0.012	< 0.0004	0.023	0.0005
TI	< 0.058	< 0.0100	< 0.033	< 0.100	< 0.0035	< 0.24	< 0.0053
CA	0.78	< 13.	< 2.5	0.78 TO 15.	0.027 TO 0.53	4.0	0.089
K	< 0.080	2.8	< 0.52	2.8	0.097	< 35.	< 0.79
S	3.5	100.	53.	160.	5.4	380.	8.6
P	0.13	1.5	< 0.32	1.6	0.055	4.5	0.099
SI	2.4	< 3.1	< 2.5	2.4 TO 5.6	0.083 TO 0.19	< 18.	< 0.40
AL	< 0.12	< 1.1	< 0.49	< 1.7	< 0.060	3.1	0.069
MG	< 0.13	< 0.0052	< 0.0045	< 0.14	< 0.0050	< 18.	< 0.40
NA	1.1	< 13.	< 6.8	1.1 TO 20.	0.037 TO 0.69	240.	5.3
B	0.54	0.0096	0.055	0.61	0.021	< 0.23	< 0.0051
BE	< 0.0003	< 0.0019	< 0.0001	< 0.0001 TO 0.0022	< 0.0001 TO 0.0001	< 0.0008	< 0.0001
LI	< 0.0021	0.0044	0.0008	0.0053	0.0002	0.024	0.0005

TABLE D-14. SSMS DATA FOR DISTILLATE OIL RECIPROCATING ENGINE (SITE 312)

SITE 312: VOLUME SAMPLED = 29.95 DSCM

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0036	< 0.069	< 0.038	< 0.11	< 0.0037	< 0.48	< 0.020
TH	< 0.0035	< 0.067	< 0.037	< 0.11	< 0.0036	< 0.46	< 0.019
BI	< 0.0032	< 0.060	< 0.034	< 0.097	< 0.0032	< 0.42	< 0.017
PB	1.4	< 0.52	0.058	1.5	0.050	< 7.4	< 0.31
TL	< 0.0031	< 0.059	< 0.033	< 0.095	< 0.0032	< 0.41	< 0.017
AU	< 0.0030	< 0.057	< 0.032	< 0.091	< 0.0031	< 0.39	< 0.016
IR	< 0.0029	< 0.055	< 0.031	< 0.089	< 0.0030	< 0.38	< 0.016
OS	< 0.0029	< 0.055	< 0.031	< 0.088	< 0.0029	< 0.38	< 0.016
RE	< 0.0028	< 0.054	< 0.030	< 0.086	< 0.0029	< 0.37	< 0.016
W	< 0.0028	< 0.053	< 0.030	< 0.085	< 0.0028	< 0.37	< 0.015
HF	< 0.0027	< 0.051	< 0.029	< 0.083	< 0.0028	< 0.36	< 0.015
LU	< 0.0027	< 0.050	< 0.028	< 0.081	< 0.0027	< 0.35	< 0.015
YB	< 0.0026	< 0.050	< 0.028	< 0.080	< 0.0027	< 0.35	< 0.014
TM	< 0.0026	< 0.049	< 0.027	< 0.078	< 0.0026	< 0.34	< 0.014
ER	< 0.0026	< 0.048	< 0.027	< 0.078	< 0.0026	< 0.33	< 0.014
HO	< 0.0025	< 0.047	< 0.026	< 0.076	< 0.0026	< 0.33	< 0.014
DY	< 0.0025	< 0.047	< 0.026	< 0.075	< 0.0025	< 0.33	< 0.014
TB	< 0.0024	< 0.046	< 0.026	< 0.074	< 0.0025	< 0.32	< 0.013
GD	< 0.0024	< 0.045	< 0.025	< 0.073	< 0.0024	< 0.31	< 0.013
EU	< 0.0023	< 0.044	< 0.024	< 0.071	< 0.0024	< 0.30	< 0.013
SM	< 0.0023	< 0.043	< 0.024	< 0.070	< 0.0023	< 0.30	< 0.013
ND	< 0.0022	< 0.042	< 0.023	< 0.067	< 0.0022	< 0.29	< 0.012
PR	< 0.0022	< 0.041	< 0.023	< 0.065	< 0.0022	< 0.28	< 0.012
CE	0.0012	< 0.040	< 0.023	0.0012 TO 0.063	< 0.0001 TO 0.0021	< 0.28	< 0.012
LA	< 0.0018	< 0.040	< 0.022	< 0.064	< 0.0021	< 0.28	< 0.012
BA	0.33	< 0.56	< 0.039	0.33	0.011	0.58	0.024
CS	< 0.0001	< 0.038	0.0005	0.0005 TO 0.038	< 0.0001 TO 0.0013	0.0078	0.0003
I	0.0012	< 0.037	0.018	0.020	0.0006	0.087	0.0036
TE	< 0.0019	< 0.037	< 0.020	< 0.059	< 0.0020	< 0.26	< 0.011
SB	0.015	< 0.025	0.019	0.033	0.0011	1.5	0.064
SN	0.11	< 0.074	< 0.96	0.11 TO 1.0	0.0038 TO 0.034	0.45	0.019
CD	0.016	0.070	0.046	0.13	0.0044	< 0.24	< 0.0100
PD	< 0.0016	< 0.031	< 0.017	< 0.049	< 0.0016	< 0.21	< 0.0089
RH	< 0.0016	< 0.030	< 0.017	< 0.048	< 0.0016	< 0.21	< 0.0086

- Continued -

SITE 312: VOLUME SAMPLED = 29.95 DSCM

TABLE D-14 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0015	< 0.029	< 0.016	< 0.047	< 0.0016	< 0.20	< 0.0084
MO	0.027	0.067	0.022	0.12	0.0039	0.46	0.019
NB	< 0.0014	< 0.027	0.0032	0.0032 TO 0.028	0.0001 TO 0.0009	0.060	0.0025
ZR	0.015	< 0.026	< 0.015	0.015 TO 0.041	0.0005 TO 0.0014	< 0.041	< 0.0017
Y	0.0007	< 0.026	< 0.014	0.0007 TO 0.040	< 0.0001 TO 0.0013	< 0.18	< 0.0074
SR	0.15	< 0.18	0.0100	0.16	0.0052	< 0.12	< 0.0052
RB	0.0014	< 0.011	0.0007	0.0022 TO 0.011	< 0.0001 TO 0.0004	0.047	0.0020
BR	0.014	< 0.094	< 0.018	0.014 TO 0.11	0.0005 TO 0.0038	< 0.18	< 0.0075
SE	0.011	0.060	0.14	0.21	0.0070	< 0.16	< 0.0066
AS	0.048	< 0.030	0.0032	0.051	0.0017	< 0.15	< 0.0063
GE	< 0.0011	< 0.021	< 0.012	< 0.034	< 0.0011	< 0.15	< 0.0061
GA	< 0.0011	< 0.020	< 0.011	< 0.032	< 0.0011	< 0.14	< 0.0058
ZN	1.5	0.46	0.90	2.8	0.094	17.	0.71
CU	0.21	< 1.1	< 0.28	0.21 TO 1.4	0.0069 TO 0.048	11.	0.47
NI	3.3	< 2.9	< 0.21	3.3	0.11	20.	0.83
CO	0.016	< 0.031	0.0098	0.026	0.0008	0.16	0.0069
FE	30.	5.2	< 1.7	35.	1.2	< 15.	< 0.63
MN	0.40	< 0.78	< 0.22	0.40 TO 1.0	0.014 TO 0.033	0.89	0.037
CR	0.043	< 0.24	0.098	0.14	0.0047	1.4	0.060
V	0.0048	< 0.0063	0.0018	0.0066	0.0002	0.034	0.0014
TI	0.068	0.037	< 0.17	0.11	0.0035	< 0.83	< 0.035
CA	16.	< 12.	< 2.2	16.	0.54	6.0	0.25
K	0.55	< 9.6	< 0.33	0.55 TO 9.9	0.019 TO 0.33	< 9.1	< 0.38
S	99.	< 28.	130.	230.	7.7	600.	25.
P	0.52	< 2.1	< 0.15	0.52 TO 2.3	0.017 TO 0.075	< 4.0	< 0.17
SI	13.	< 2.1	< 0.61	13.	0.43	< 16.	< 0.65
AL	< 0.80	< 0.63	< 0.84	< 2.3	< 0.076	< 5.0	< 0.21
MG	0.71	< 2.0	< 0.40	0.71 TO 2.5	0.024 TO 0.082	< 3.9	< 0.16
NA	< 2.3	< 11.	< 3.3	< 16.	< 0.54	< 67.	< 2.8
B	0.62	< 0.21	0.18	0.80	0.027	< 0.19	< 0.0081
BE	< 0.0001	< 0.0026	0.0001	0.0001 TO 0.0026	< 0.0001 TO 0.0001	< 0.0004	< 0.0001
LI	< 0.011	< 0.063	0.0005	0.0005 TO 0.074	< 0.0001 TO 0.0025	0.033	0.0014

SITE 313: VOLUME SAMPLED = 30.10 DSCM

TABLE D-15. SSMS DATA FOR DISTILLATE OIL RECIPROCATING ENGINE (SITE 313)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
U	< 0.0049	< 0.059	< 0.038	< 0.100	< 0.0034	< 0.48	< 0.015
TH	< 0.0047	< 0.058	< 0.037	< 0.099	< 0.0033	< 0.46	< 0.015
BI	0.0013	< 0.052	< 0.033	0.0013 TO 0.085	< 0.0001 TO 0.0028	< 0.42	< 0.013
PB	0.37	0.54	0.14	1.1	0.035	< 3.3	< 0.100
TL	< 0.0042	< 0.051	< 0.032	< 0.087	< 0.0029	< 0.41	< 0.013
AU	< 0.0040	< 0.049	< 0.031	< 0.084	< 0.0028	< 0.39	< 0.012
IR	< 0.0039	< 0.048	< 0.030	< 0.082	< 0.0027	< 0.38	< 0.012
OS	< 0.0039	< 0.047	< 0.030	< 0.081	< 0.0027	< 0.38	< 0.012
RE	< 0.0038	< 0.046	< 0.029	< 0.079	< 0.0026	< 0.37	< 0.012
W	< 0.0037	< 0.046	< 0.029	< 0.075	< 0.0025	< 0.37	< 0.012
HF	< 0.0036	< 0.044	< 0.028	< 0.076	< 0.0025	< 0.36	< 0.011
LU	< 0.0036	< 0.043	< 0.028	< 0.075	< 0.0025	< 0.35	< 0.011
YB	< 0.0035	< 0.043	< 0.027	< 0.074	< 0.0025	< 0.35	< 0.011
TM	< 0.0034	< 0.042	< 0.027	< 0.072	< 0.0024	< 0.34	< 0.011
ER	< 0.0034	< 0.041	< 0.027	< 0.071	< 0.0024	< 0.33	< 0.011
HO	< 0.0034	< 0.041	< 0.026	< 0.070	< 0.0023	< 0.33	< 0.0100
DY	< 0.0033	< 0.040	< 0.026	< 0.069	< 0.0023	< 0.33	< 0.0100
TB	< 0.0032	< 0.039	< 0.025	< 0.068	< 0.0023	< 0.32	< 0.0100
GD	< 0.0032	< 0.039	< 0.025	< 0.067	< 0.0022	< 0.31	< 0.0099
EU	< 0.0031	< 0.038	< 0.024	< 0.065	< 0.0022	< 0.30	< 0.0096
SM	< 0.0031	< 0.037	< 0.024	< 0.064	< 0.0021	< 0.30	< 0.0095
ND	0.0002	< 0.036	< 0.023	0.0002 TO 0.059	< 0.0001 TO 0.0019	< 0.29	< 0.0091
PR	< 0.0001	< 0.035	< 0.022	< 0.057	< 0.0019	< 0.28	< 0.0089
CE	< 0.0004	< 0.035	< 0.022	< 0.058	< 0.0019	< 0.28	< 0.0088
LA	< 0.0004	< 0.034	< 0.022	< 0.057	< 0.0019	< 0.28	< 0.0087
BA	< 0.28	< 0.46	< 0.047	< 0.79	< 0.026	1.5	0.048
CS	< 0.0001	< 0.033	0.0019	0.0019 TO 0.033	< 0.0001 TO 0.0011	< 0.27	< 0.0084
I	0.0003	0.0070	0.0086	0.016	0.0005	< 0.25	< 0.0080
TE	< 0.0026	< 0.032	< 0.020	< 0.054	< 0.0018	< 0.26	< 0.0080
SB	0.0027	0.011	0.048	0.062	0.0020	0.21	0.0065
SN	0.058	0.027	1.6	1.7	0.057	< 0.48	< 0.015
CD	< 0.0023	0.19	0.079	0.27	0.0091	< 0.30	< 0.0095
PD	< 0.0022	< 0.026	< 0.017	< 0.045	< 0.0015	< 0.21	< 0.0067
RH	< 0.0021	< 0.026	< 0.016	< 0.044	< 0.0015	< 0.21	< 0.0065

- Continued -

SITE 313: VOLUME SAMPLED = 30.10 DSCM

TABLE D-15 (Continued)

ELEMENT	FILTER CATCH (MG)	XAD RESIN (MG)	COMPOSITE SAMPLE (MG)	TOTAL SASS (MG)	EMISSION FOUND (MG/DSCM)	FUEL (PPM)	EMISSION CALCULATED (MG/DSCM)
RU	< 0.0021	< 0.025	< 0.016	< 0.043	< 0.0014	< 0.20	< 0.0064
MO	0.0081	0.041	0.052	0.100	0.0034	< 0.15	< 0.0046
NB	< 0.0001	< 0.023	< 0.015	< 0.038	< 0.0013	< 0.19	< 0.0058
ZR	0.0079	< 0.023	< 0.014	0.0079 TO 0.037	0.0003 TO 0.0012	< 0.18	< 0.0057
Y	0.0091	< 0.022	< 0.014	0.0001 TO 0.036	< 0.0001 TO 0.0012	< 0.18	< 0.0056
SR	0.064	0.045	0.012	0.12	0.0040	0.089	0.0028
RB	0.0098	0.0098	0.0016	0.012	0.0004	< 0.025	< 0.0008
BR	< 0.011	0.18	0.017	0.19	0.0064	< 0.16	< 0.0050
SE	< 0.0011	< 0.073	0.46	0.46	0.015	< 0.16	< 0.0050
AS	0.012	< 0.037	0.0053	0.015 TO 0.037	0.0005 TO 0.0012	< 0.047	< 0.0015
GE	< 0.0015	< 0.018	< 0.011	< 0.031	< 0.0010	< 0.15	< 0.0046
GA	< 0.0014	< 0.017	< 0.011	< 0.030	< 0.0010	< 0.14	< 0.0044
ZN	1.8	< 1.3	1.2	3.1	0.100	< 7.2	< 0.23
CU	0.14	< 2.4	0.25	0.39 TO 2.4	0.013 TO 0.081	19.	0.60
NI	0.78	0.71	0.60	2.1	0.070	8.1	0.26
CO	< 0.0065	0.021	0.032	0.053	0.0017	< 0.097	< 0.0031
FE	3.5	240.	9.8	260.	8.5	< 25.	< 0.79
MN	< 0.037	0.19	0.23	0.41	0.014	< 0.62	< 0.020
CR	0.030	< 0.045	0.23	0.26	0.0087	< 0.17	< 0.0053
V	0.0008	0.0040	0.0066	0.011	0.0004	< 0.059	< 0.0019
TI	< 0.065	0.033	0.0047	0.038	0.0013	< 0.23	< 0.0073
CA	12.	< 10.	1.5	13.	0.43	32.	1.0
K	0.31	< 6.9	0.35	0.66 TO 6.9	0.022 TO 0.23	< 30.	< 0.95
S	13.	35.	310.	360.	12.	330.	10.
P	0.19	< 1.8	0.27	0.46 TO 1.8	0.015 TO 0.060	5.4	0.17
SI	< 6.0	< 1.8	0.45	0.45 TO 7.8	0.015 TO 0.26	< 37.	< 1.2
AL	< 0.96	< 0.65	1.1	1.1	0.037	2.6	0.081
MG	< 0.0005	< 1.4	0.32	0.32 TO 1.8	0.011 TO 0.059	< 18.	< 0.57
NA	< 3.8	< 37.	< 1.7	< 42.	< 1.4	< 56.	< 1.8
B	< 0.13	0.089	0.042	0.13	0.0043	< 0.89	< 0.028
BE	< 0.0001	< 0.0002	< 0.0001	< 0.0001 TO 0.0002	< 0.0001 TO 0.0001	0.0013	< 0.0001
LI	< 0.0011	< 0.014	0.0018	0.0018 TO 0.015	< 0.0001 TO 0.0005	0.091	0.0029

TABLE D-16. LEVEL II ORGANIC ANALYSIS RESULTS - COMPOUNDS FOUND IN SAMPLE 309-2-XRPF-MRPR

Compound	Amount ($\mu g/m^3$)	Scan No.
Toluene	*	5
Xylene	14 †	45
Xylene	56 †	50
Xylene	30 †	65
C_3 Cyclohexane	54	69
n-C_9 Hydrocarbon (Nonane)	38	78
Benzaldehyde	48	111
C_3 Benzene	24	118
C_3 Benzene	110	127
C_3 Benzene	100	136
C_{10} Branched (Hydrocarbon)	46	154
C_3 Benzene	320	169
C_{10} Unsaturated (Hydrocarbon)	78	179
n-C_{10} Hydrocarbon (Decane)	220	199
C_3 Benzene	86	209
Methyl Styrene	20	226
C_{11} Branched (Hydrocarbon)	16	233
C_{11} Branched (Hydrocarbon)	34	240
C_5 Cyclohexane	12	247
C_3 Benzene	96	267
C_3 Benzene	100	274
C_4 Benzene	140 †	282

- Continued -

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* Equal to or less than amount found in blank.

† Corrected for blank concentration, amount actually present in sample rather questionable due to blank level variations.

TABLE D-16. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
C_4 Benzene	18 †	296
C_4 Benzene	310 †	322
C_4 Benzene	100 †	341
Methyl Benzoate	*	344
C_{11} Branched (Hydrocarbon)	110	346
C_4 Benzene	260 †	394
n-C_{11} Hydrocarbon (Undecane)	780	440
C_4 Unsaturated (Benzene)	86	480
C_5 Benzene	110	492
C_3 Benzene	30	147
C_5 Benzene	410	522
C_5 Benzene	100	542
C_5 Benzene	20	554
C_5 Benzene	52	570
C_5 Benzene	8	584
Naphthalene	170 †	596
C_5 Benzene	84	610
C_{12} Branched (Hydrocarbon)	54	623
C_{12} Branched (Hydrocarbon)	280	639
C_{12} Branched (Hydrocarbon)	140	657
C_5 Benzene	84	682
C_{12} Unsaturated Hydrocarbon	240	711

- Continued -

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* Equal to or less than amount found in blank.

† Corrected for blank concentration, amount actually present in sample rather questionable due to blank level variations.

TABLE D-16. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
n-C_{12} Hydrocarbon (Dodecane)	780	752
Methyl Tetrahydronaphthalene	42	763
C_{13} Branched (Hydrocarbon)	160	789
C_{13} Unsaturated Hydrocarbon	62	798
C_{13} Branched Hydrocarbon	62	807
C_6 Benzene	8	817
C_6 Benzene	56	825
C_6 Benzene	32	852
C_{13} Branched Hydrocarbon	46	891
Methyl Naphthalene	300	906
C_{13} Branched Hydrocarbon	130	918
C_{13} Branched Hydrocarbon	36	932
Methyl Naphthalene	160	939
Unknown Substituted Cyclohexane	10	957
Unknown	14	964
C_{13} Unsaturated Hydrocarbon	140	973
n-C_{13} Hydrocarbon (Tridecane)	1000	1007
C_{14} Branched Hydrocarbon	12	1024
C_3 Tetrahydronaphthalene	28	1030
C_{14} Branched Hydrocarbon	68	1041

- Continued -

TABLE D-16. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
Unknown	2	1047
Unknown	14	1052
C_3 Tetrahydronaphthalene	20	1064
Unknown Substituted Cyclohexane	82	1075
Chloronaphthalene	Internal Standard	1083
Biphenyl	Trace	1092
C_{14} Branched Hydrocarbon	74	1113
C_{14} Unsaturated Hydrocarbon	18	1120
C_2 Naphthalene	10	1126
C_{14} Branched Hydrocarbon	36	1130
C_{14} Branched Hydrocarbon	130	1142
C_2 Naphthalene	290	1156
C_{14} Branched Hydrocarbon	120	1171
C_2 Naphthalene	24	1181
C_2 Naphthalene	130	1186
n-C_{14} Hydrocarbon (Tetradecane)	980	1221
Unknown aromatic	100	1229
C_2 Naphthalene	20	1249
Unknown Acid Ester	32	1260
C_{15} Branched Hydrocarbon	40	1275
C_2 Naphthalene	32	1291
Unknown Aromatic	32	1300

- Continued -

TABLE D-16. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
C_{15} Branched Hydrocarbon	180	1318
C_{15} Branched Hydrocarbon	84	1334
C_{15} Branched Hydrocarbon	310	1347
C_3 Naphthalene	120	1357
C_3 Naphthalene	40	1363
C_3 Naphthalene	52	1379
C_3 Naphthalene	110	1394
n-C_{15} Hydrocarbon (Pentadecane)	1000	1420
C_3 Naphthalene	38	1432
C_3 Naphthalene	130	1439
C_3 Naphthalene	140	1467
C_{16} Unsaturated Hydrocarbon	68	1483
C_4 Naphthalene	120	1502
C_{16} Unsaturated Hydrocarbon	40	1513
C_{16} Unsaturated Hydrocarbon	70	1525
C_4 Naphthalene	82	1534
C_{16} Branched Hydrocarbon	96	1545
C_4 Naphthalene	40	1571
C_4 Naphthalene	110	1586
n-C_{16} Hydrocarbon (Hexadecane)	990	1604
C_{17} Unsaturated Hydrocarbon	90	1615
C_4 Naphthalene	78	1630
n-C_{17} Branched Hydrocarbon	58	1645
Methoxybiphenyl	48	1663
C_4 Naphthalene	32	1682

- Continued -

TABLE D-16. (Continued)

Compound	Amount (μg/m^3)	Scan No.
C_{17} Branched Hydrocarbon	190	1695
C_{17} Branched Hydrocarbon	26	1709
C_{17} Branched Hydrocarbon	62	1720
C_{17} Branched Hydrocarbon	100	1735
C_5 Naphthalene	34	1749
C_5 Naphthalene	20	1763
C_5 Naphthalene	52	1778
n-C_{17} Hydrocarbon (Heptadecane)	820	1806
C_{18} Branched Hydrocarbon	400	1822
C_3 Biphenyl	16	1837
Phenanthrene (or Isomer)	94	1852
Unknown	16	1867
C_5 Naphthalene	14	1881
Unknown Substituted Cyclohexane	76	1901
C_{18} Branched Hydrocarbon	46	1911
C_{18} Branched Hydrocarbon	48	1930
C_{18} Branched Hydrocarbon	56	1945
Ethyl Fluorene (or Isomer)	24	1955
n-C_{18} Hydrocarbon (Octadecane)	650	2007
C_{19} Unsaturated Hydrocarbon	170	2028
Methylphenanthrene (or Isomer)	86	2088
C_{19} Branched Hydrocarbon	66	2123
n-C_{19} Hydrocarbon (Nonadecane)	490	2192
C_{20} Branched Hydrocarbon	42	2263

- Continued -

TABLE D-16. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
Pyrene (or Isomer)	Trace	2301
n-C_{20} Hydrocarbon (Eicosane)	310	2360
n-C_{21} Hydrocarbon (Heneicosane)	130	2524
n-C_{22} Hydrocarbon (Docosane)	76	2677
Dioctylphthalate	(a)	3080

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* Equal to or less than amount found in blank.

TABLE D-17. LEVEL II ORGANIC ANALYSIS RESULTS - COMPOUNDS FOUND IN SAMPLE #309-2-CD-LE

Compound	Amount ($\mu g/m^3$)	Scan No.
Benzene	*	20
n-C_7 Hydrocarbon (Heptane)	1	32
Methyl Cyclohexane	*	44
Toluene	*	68
Unknown Unsat. Hydrocarbon	0 .5	395
Silicone	1	517
Naphthalene	0 .5	841
Silicone	3	894
n-C_{12} Hydrocarbon (Dodecane)	0 .2	944
Methyl Naphthalene	0 .2	1078
Methyl Naphthalene	0 .2	1115
n-C_{13} Hydrocarbon (Tridecane)	0 .6	1178
Chloronaphthalene	Internal Standard	1278
Silicone	15	1307
n-C_{14} Hydrocarbon (Tetradecane)	2	1418
n-C_{15} Hydrocarbon (Pentadecane)	2	1628
Dichloronaphthalene	I.S. Impurity	1649
Trimethylnaphthalene	1	1656
Silicone	38	1683
n-C_{16} Hydrocarbon (Hexadecane)	3	1818
C_{17} Branched Hydrocarbon	1	1911
n-C_{17} Hydrocarbon (Heptadecane)	16	1994
C_{18} Branched Hydrocarbon	2	2012
Silicone	2	2090

- Continued -

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* Equal to or less than amount found in blank.

TABLE D-17. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
n-C_{18} Hydrocarbon (Octadecane)	4	2158
C_{19} Branched Hydrocarbon	1	2179
Silicone	10	2261
n-C_{19} Hydrocarbon (Nonadecane)	2	2314
Dibutylphthalate	1	2337
n-C_{20} Hydrocarbon (Eicosane)	1	2465
Silicone	5	2486
Silicone	6	2501
n-C_{21} Hydrocarbon (Heneicosane)	0.5	2610
Silicone	6	2727
Silicone	5	2935
Silicone	6	3132
Dioctylphthalate	3	3154
Silicone	11	3321
Silicone	9	3400
Silicone	19	3445

TABLE D-18. LEVEL II ORGANIC ANALYSIS RESULTS - COMPOUNDS FOUND IN SAMPLE #312-2-XRPF-MRPR

Compound	Amount ($\mu g/m^3$)	Scan No.
Benzene	*	20
Methylcyclohexane	*	40
Toluene	*	64
Xylene	24	163
Xylene	54	175
Xylene	26	207
Cyclohexane	26	216
C_9 Unsat. Hydrocarbon	24	226
n-C_9 Hydrocarbon (Nonane)	66	245
C_3 Benzene	18	261
Cyclohexane	26	285
Benzaldehyde	12	299
C_{10} Branched Hydrocarbon	38	306
C_{10} Branched Hydrocarbon	4	318
C_3 Benzene	80	325
C_3 Benzene	42	341
C_3 Benzene	44	357
C_{10} Branched Hydrocarbon	30	362
C_{10} Branched Hydrocarbon	32	374
C_3 Benzene	120	386
C_{10} Unsat. Hydrocarbon	62	392
C_{10} Unsat. Hydrocarbon	60	409
C_4 Benzene	18	420
n-C_{10} Hydrocarbon (Decane)	250	437
C_4 Benzene	22	445
Dihydroindene	15	459

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* Equal to or less than amount found in blank.

TABLE D-18. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
Unknown	12	467
C_{11} Branched Hydrocarbon	72	484
C_{11} Unsat. Hydrocarbon	18	495
C_4 Benzene	48 †	506
C_4 Benzene	62 †	515
C_4 Benzene	28 †	521
C_4 Benzene	25 †	534
C_{11} Branched Hydrocarbon	12	542
Methyl Benzoate	*	547
C_{11} Unsat. Hydrocarbon	80	557
C_{11} Branched Hydrocarbon	110	560
C_{11} Branched Hydrocarbon	160	570
C_{11} Branched Hydrocarbon	80	581
C_{11} Unsat. Hydrocarbon	160	616
n-C_{11} Hydrocarbon (Undecane)	570	647
Decahydronaphthalene, 2-Methyl	44	671
C_5 Benzene	38	681
C_5 Benzene	180	702
C_5 Benzene	14	716
C_5 Benzene	22	734
Naphthalene	58 †	752
C_{12} Branched Hydrocarbon	86	761
C_{12} Branched Hydrocarbon	34	769
C_{12} Branched Hydrocarbon	162	781
C_{12} Branched Hydrocarbon	64	792

- Continued -

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* Equal to or less than amount found in blank.

† Corrected for blank concentration. Amount actually present in sample rather questionable due to blank level variations.

TABLE D-18. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
C_5 Benzene	36	810
C_5 Benzene	110	831
n-C_{12} Hydrocarbon (Dodecane)	400	859
C_6 Benzene	10	870
C_6 Benzene	12	881
C_{13} Branched Hydrocarbon	114	888
Methyl Tetrahydronaphthalene	96	939
C_{13} Branched Hydrocarbon	62	970
Methylnaphthalene	330	989
Methylnaphthalene	240	1015
n-C_{13} Hydrocarbon (Tridecane)	470	1071
Chloronaphthalene	Internal Standard	1152
C_2 Unsat. Naphthalene	20	1158
C_2 Naphthalene	22	1190
C_2 Naphthalene	130	1219
C_2 Naphthalene	82	1227
C_2 Naphthalene	350	1247
n-C_{14} Hydrocarbon (Tetradecane)	440	1274
C_2 Naphthalene	140	1279
C_2 Naphthalene	54	1305
C_3 Unsat. Naphthalene	78	1366
C_{15} Unsat. Hydrocarbon	170	1392
n-C_{15} Hydrocarbon (Pentadecane)	490	1459
C_3 Naphthalene	44	1484
C_3 Naphthalene	72	1544
C_{16} Branched Hydrocarbon	60	1560
C_3 Naphthalene	72	1575

- Continued -

TABLE D-18. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
C_{16} Branched Hydrocarbon	120	1619
n-C_{16} Hydrocarbon (Hexadecane)	350	1634
C_{17} Branched Hydrocarbon	48	1663
C_{17} Branched Hydrocarbon	190	1723
n-C_{17} Hydrocarbon (Heptadecane)	260	1809
C_{13} Unsat. Hydrocarbon	200	1825
Phenanthrene (or isomer)	28	1862
Phenanthrene (or isomer)	10	1867
n-C_{18} Hydrocarbon (Octadecane)	220	1973
C_{19} Branched Hydrocarbon	100	1993
Methylphenanthrene (or isomer)	22	2062
n-C_{19} Hydrocarbon (Nonadecane)	200	2135
n-C_{20} Hydrocarbon (Eicosane)	100	2288
n-C_{21} Hydrocarbon (Heneicosane)	66	2435
Dioctylphthalate	42†	2948

TABLE D-19. LEVEL II ORGANIC ANALYSIS RESULTS - COMPOUNDS FOUND IN SAMPLE 312-2-CD-LE

Compound	Amount ($\mu g/m^3$)	Scan No.
Benzene	*	23
Methyl Cyclohexane	*	42
Toluene	*	58
Chloronaphthalene	Internal Standard	111
n-C_{14} Hydrocarbon (Tetradecane)	1	1247
n-C_{15} Hydrocarbon (Pentadecane)	2	1451
n-C_{16} Hydrocarbon (Hexadecane)	4	1636
C_{17} Branched Hydrocarbon	1	1731
n-C_{17} Hydrocarbon (Heptadecane)	6	1811
C_{18} Branched Hydrocarbon	2	1828
n-C_{18} Hydrocarbon (Octadecane)	6	1977
C_{19} Branched Hydrocarbon	2	1997
n-C_{19} Hydrocarbon (Nonadecane)	4	2133
n-C_{20} Hydrocarbon (Eicosane)	2	2288
n-C_{21} Hydrocarbon (Heneicosane)	2	2438
n-C_{22} Hydrocarbon (Docosane)	Trace	2582
Dioctylphthalate	6	2983

* Equal to or less than amount found in blank.

Trace - Detected but too low to quantitate (0.05 - 1.0 $\mu g/m^3$).

TABLE D-20. LEVEL II ORGANIC ANALYSIS RESULTS - COMPOUNDS FOUND IN SAMPLE #313-2-XRPF-MRPR

Compound	Amount ($\mu g/m^3$)	Scan No.
Benzene	*	23
Methylcyclohexane	*	43
Toluene	*	69
C_9 Unsat. Hydrocarbon	16	100
C_2 Benzene	38	172
C_2 Benzene	110	184
C_9 Branched Hydrocarbon	12	198
C_2 Benzene	56	215
C_3 Cyclohexane	62	224
C_9 Unsat. Hydrocarbon	64	234
n-C_9 Hydrocarbon (Nonane)	170	253
C_3 Benzene	38	271
C_4 Cyclohexane	48	294
C_{10} Branched Hydrocarbon	240	315
C_{10} Branched Hydrocarbon	200	339
C_3 Benzene	76	351
C_3 Benzene	66	370
C_{10} Unsat. Hydrocarbon	44	387
C_3 Benzene	320	399
C_{10} Unsat. Hydrocarbon	150	423
C_3 Benzene	34	435
n-C_{10} Hydrocarbon (Decane)	250	450
C_3 Benzene	30	454
C_4 Benzene	40	458
C_{11} Branched Hydrocarbon	140	499
C_{11} Unsat. Hydrocarbon	40	510

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* Equal to or less than amount found in blank.

TABLE D-20. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
C_4 Benzene	78†	522
C_4 Benzene	128†	531
C_4 Benzene	40†	538
C_4 Benzene	34†	552
Methylbenzoate	*	556
C_4 Benzene	10†	559
C_4 Benzene	190	578
C_{11} Unsat. Hydrocarbon	290	589
C_{11} Branched Hydrocarbon	120	601
C_{11} Unsat. Hydrocarbon	630	638
n-C_{11} Hydrocarbon (Undecane)	950	668
C_{12} Branched Hydrocarbon	140	704
C_5 Benzene	22	725
C_5 Benzene	42	736
C_5 Benzene	68	766
Naphthalene	220†	778
C_{12} Unsat. Hydrocarbon	66	793
C_2 Indene	150	803
C_2 Indene	66	814
C_{12} Unsat. Hydrocarbon	340	853
n-C_{12} Hydrocarbon (Dodecane)	680	881
C_{13} Unsat. Hydrocarbon	200	910
C_{13} Branched Hydrocarbon	66	925
Unknown Substituted Cyclohexane	80	940
Tetrahydromethyl Naphthalene	150	955
C_{13} Branched Hydrocarbon	120	991

- Continued -

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* Equal to or less than amount found in blank.

† Corrected for blank concentration. Amount actually present in sample rather questionable due to blank level variations.

TABLE D-20. (Continued)

Compound	Amount (μg/m^3)	Scan No.
Methylnaphthalene	450	1011
C_{13} Unsat. Hydrocarbon	120	1027
C_{13} Unsat. Hydrocarbon	328	1036
Methylnaphthalene	140	1042
C_{13} Unsat. Hydrocarbon	48	1061
C_2 Tetrahydronaphthalene	82	1072
n-C_{13} Hydrocarbon (Tridecane)	810	1088
Chloronaphthalene	Internal Standard	1170
Biphenyl	36	1174
C_{14} Branched Hydrocarbon	130	1190
C_2 Naphthalene	150	1207
C_{14} Branched Hydrocarbon	160	1216
C_2 Naphthalene	210	1234
C_{14} Branched Hydrocarbon	150	1246
C_2 Naphthalene	560	1263
n-C_{14} Hydrocarbon (Tetradecane)	840	1291
C_2 Naphthalene	20	1298
Unknown	76	1307
C_2 Naphthalene	150	1322
C_{15} Branched Hydrocarbon	54	1353
C_{15} Branched Hydrocarbon	140	1366
Methyl Biphenyl	120	1383
Methyl Biphenyl	30	1399
C_{15} Branched Hydrocarbon	350	1411
C_3 Naphthalene	180	1424
C_3 Naphthalene	150	1468
n-C_{15} Hydrocarbon (Pentadecane)	1000	1483

- Continued -

TABLE D-20. (Continued)

Compound	Amount ($\mu g/m^3$)	Scan No.
C_3 Naphthalene	130	1512
C_3 Naphthalene	120	1533
C_3 Naphthalene	92	1571
C_{16} Branched Hydrocarbon	140	1586
Methyl Biphenyl	130	1600
Unknown	100	1630
Alkyl Subst. Cyclopentanedione	160	1645
n-C_{16} Hydrocarbon (Hexadecane)	690	1665
C_4 Naphthalene	28	1746
C_{17} Hydrocarbon Branched	410	1758
C_{17} Hydrocarbon Branched	98	1775
C_{17} Unsat. Hydrocarbon	100	1821
n-C_{17} Hydrocarbon (Heptadecane)	540	1834
C_{18} Unsat. Hydrocarbon	500	1855
Phenanthrene (or Isomer)	92	1893
n-C_{18} Hydrocarbon (Octadecane)	580	2009
C_{19} Branched Hydrocarbon	260	2028
Methylphenanthrene (or isomer)	Trace	2088
n-C_{19} Hydrocarbon (Nonadecane)	490	2169
n-C_{20} Hydrocarbon (Eicosane)	360	2321
Pyrene (or isomer)	Trace	2410
n-C_{21} Hydrocarbon (Heneicosane)	210	2470
n-C_{22} Hydrocarbon (Doeicosane)	110	2616
Dioctylphthalate	1200†	3013

† Corrected for blank concentration. Amount actually present in sample rather questionable due to blank level variations.

Trace - Detected but too low to quantitate (0.05 - 1.0 $\mu g/m^3$).

TABLE D-21. LEVEL II ORGANIC ANALYSIS RESULTS - COMPOUNDS FOUND IN SAMPLE 313-2-CD-LE

Compound	Amount (($\mu g/m^3$)	Scan No.
Benzene	*	27
Methylcyclohexane	*	45
Toluene	*	92
Chloronaphthalene	Internal Standard	1259
C_{14} Branched Hydrocarbon	2	1541
n-C_{14} Hydrocarbon (Tetradecane)	2	1582
n-C_{15} Hydrocarbon (Pentadecane)	2	1765
n-C_{16} Hydrocarbon (Hexadecane)	2	1938
C_{17} Branched Hydrocarbon	2	1957
n-C_{17} Hydrocarbon (Heptadecane)	1	2107
n-C_{18} Hydrocarbon (Octadecane)	2	2270
Dioctylphthalate	22	3188

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* Equal to or less than amount found in blank.

METRIC CONVERSION FACTORS AND PREFIXES

CONVERSION FACTORS

To convert from	To	Multiply by
Degrees Celsius (°C)	Degrees Fahrenheit (°F)	$t(°F) = 1.8\ t(°C) + 32$
Joule (J)	Btu	9.478×10^{-4}
Kilogram (kg)	Pound-mass (avoirdupois)	2.205
Kilojoule/kilogram (kJ/kg)	Btu/lb_m	4.299×10^{-1}
Megagram (Mg)	Ton (2000 lb_m)	1.102
Megawatt (MW)	Horsepower (HP)	1.341×10^{3}
Meter (m)	Foot (ft)	3.281
$Meter^3$ (m^3)	Barrel (bbl)	6.290
$Meter^3$ (m^3)	$Foot^3$ (ft^3)	3.531×10^{1}
$Meter^3$ (m^3)	Gallon (gal)	2.642×10^{2}
Nanogram/joule (ng/J)	lb_m/million Btu	2.326×10^{-3}
Picogram/joule (pg/J)	lb_m/million Btu	2.326×10^{-6}

PREFIXES

Prefix	Symbol	Multiplication Factor	Example
Peta	P	10^{15}	1 Pm = 1 x 10^{15} meters
Tera	T	10^{12}	1 Tm = 1 x 10^{12} meters
Giga	G	10^{9}	1 Gm = 1 x 10^{9} meters
Mega	M	10^{6}	1 Mm = 1 x 10^{6} meters
Kilo	k	10^{3}	1 km = 1 x 10^{3} meters
Milli	m	10^{-3}	1 mm = 1 x 10^{-3} meter
Micro	µ	10^{-6}	1 µm = 1 x 10^{-6} meter
Nano	n	10^{-9}	1 nm = 1 x 10^{-9} meter
Pico	p	10^{-12}	1 pm = 1 x 10^{-12} meter